

~~2003 C.A.M. 4/24~~
Solutions Manual to Accompany

Basic Principles and Calculations in Chemical Engineering

SIXTH EDITION

~~2003 C.A.M. 4/24~~

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TYPICAL ASSIGNMENTS FOR ONE SEMESTER

Problem Assignments

All assignments are
in the 6th edition
Study Sections

1.	First Class meeting. No assignments	
2.	UNIT AND DIMENSIONS 1.4, 1.6, 1.7, 1.8	1.1
3.	DIMENSIONAL CONSISTENCY: MOLE 1.15, 1.20, 1.21, 1.31, 1.33	1.1, 1.2
4.	METHODS OF ANALYSIS AND MEASUREMENT 1.39, 1.43, 1.47, 1.52	1.3
5.	BASIS: TEMPERATURE 1.60, 1.62, 1.63, 1.68, 1.70	1.4, 1.5
6.	PRESSURE 1.90, 1.91, 1.93, 1.94	1.6
7.	STOICHIOMETRY 1.106a. c: 1.112, 1.122, 1.125	1.8, 1.9
8.	PROBLEM SOLVING 2.1, 2.4, 2.8	2.1
9.	COMPUTER USAGE Start on P1, P2, and P3	2.2
10.	Exam No. 1	
11.	No formal class meeting - Work on computer assignments.	Handouts
12.	No class meeting - continue working on computer assignments.	Handouts
13.	Class meets - turn in computer problems <u>plus</u> the evaluation form.	
14.	CONCEPT OF THE MATERIAL BALANCE 3.1, 3.2, 3.3, 3.4	3.1
15.	ANALYSIS OF MATERIAL BALANCE PROBLEMS 3.12, 3.13, 3.19, 3.20	3.2
16.	MATERIAL BALANCE PROBLEMS (NO REACTION) 3.21, 3.23, 3.24	3.3

Problem Assignments

All assignments
in the 6th ed
Study Sec

17.	MATERIAL BALANCE PROBLEMS (NO REACTION) 3.27, 3.36, 3.37	3.3
18.	MATERIAL BALANCE PROBLEMS (WITH REACTION) 3.56, 3.57, 3.58	3.4
19.	MATERIAL BALANCE PROBLEMS (WITH REACTION) 3.60, 3.63	3.4
20.	Exam No. 2	
21.	MATERIAL BALANCE PROBLEMS WITH MULTIPLE UNITS 3.71, 3.72	3.5
22.	MATERIAL BALANCE PROBLEMS WITH RECYCLE (NO REACTION) 3.86, 3.87	3.6
23.	MATERIAL BALANCE PROBLEMS WITH RECYCLE (WITH REACTION) 3.92, 3.93, 3.94	3.6
24.	IDEAL GAS AND PARTIAL PRESSURE 4.1, 4.2, 4.9, 4.18c, 4.25	4.1-1, 4.1
25.	MATERIAL BALANCES WITH IDEAL GASES 4.27, 4.28, 4.37	4.1-3
26.	COMPRESSIBILITY 4.39, 4.40, 4.41, 4.45	4.2-1
27.	EQUATIONS OF STATE 4.54, 4.55, 4.57	4.2-2
28.	GAS MIXTURES; VAPOR PRESSURE 4.50, 4.68, 4.70, 4.73a	4.2-3, 4.1
29.	Exam No. 3.	
30.	SATURATION 4.83, 4.84, 4.86	4.4
31.	EQUILIBRIA 4.88, 4.90, 4.93	4.5

Problem Assignments

All assignments are
in the 6th edition
Study Sections

32.	PARTIAL SATURATION AND HUMIDITY 4.106, 4.110	4.6
33.	MATERIAL BALANCES INVOLVING PARTIAL SATURATION 4.116, 4.117, 4.118	4.7
34.	Exam No. 4.	
35.	ENERGY: CONCEPTS, JARGON, AND UNITS 5.1, 5.7, 5.12, 5.16, 5.21	5.1-1
36.	THE ENERGY BALANCE, 5.13 a,b; 5.29 a,b; 5.71	5.1-2
37.	ENTHALPY CHANGES 5.30, 5.34, 5.36, 5.40, 5.43	5.2
38.	SOLVING ENERGY BALANCE PROBLEMS WITHOUT REACTIONS-CLOSED SYSTEMS 5.63, 5.64, 5.67	5.3
39.	Exam No. 5	
40.	SOLVING ENERGY BALANCE PROBLEMS WITHOUT REACTIONS-OPEN SYSTEMS 5.74, 5.75, 5.78	5.3
41.	SOLVING ENERGY BALANCE PROBLEMS WITH REACTIONS 5.92, 5.96b, 5.97b, 5.104 (do (1) only)	5.4-1
42.	CONTINUED 5.109, 5.123	5.4-2
43.	ADIABATIC FLAME TEMPERATURE 5.4	Example 5.25
44.	FINAL EXAM IS ON CHAPTER 5 ONLY	

Exam No. 1
(Open Book, 1 1/2 hours)

PROBLEM 1 (5%)

Hydrogen can be separated from natural gas by diffusion through a round tube. The rate of separation is given by

$$N = 2 \pi D \rho R$$

where

N = rate of transport of H_2 from the tube, g moles/(sec)(cm of length of tube)

D = diffusion coefficient

ρ = molar density of H_2 , g moles/cm³

R = log mean radius of tube, $r_2 - r_1 / \ln \left(\frac{r_2}{r_1} \right)$, with r in cm.

What are the units of D ?

PROBLEM 2 (10%)

A pallet of boxes weighing 10 tons is dropped from a lift truck from a height of 10 feet. The maximum velocity the pallet attains before hitting the ground is 6 ft/sec. How much kinetic energy does the pallet have in (ft)(lb_f) at this velocity?

PROBLEM 3 (5%)

The specific gravity of a fuel oil is 0.82. What is the density of the oil in lb/ft³? Show all units.

PROBLEM 4 (10%)

Sulfur trioxide (SO_3) can be absorbed in sulfuric acid solution to form more concentrated sulfuric acid. If the gas to be absorbed contains 55% SO_3 , 41% N_2 , 3% SO_2 , and 1% O_2 , how many parts per million of O_2 are there in the gas? (b) What is the composition of the gas on a N_2 free basis?

PROBLEM 5 (15%)

You have 100 kilograms of gas of the following composition:

CH_4	30%
H_2	10%
N_2	60%

What is the average molecular weight of this gas?

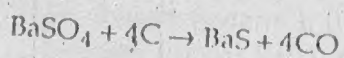
PROBLEM 6 (15%)

If the heat capacity of a substance is $5.32 \text{ J/(g)}(^{\circ}\text{C})$ and its molecular weight is 37.4, what is its heat capacity in

- (a) $\text{J/(g)}(^{\circ}\text{F})$
- (b) $\text{J/(lb)}(^{\circ}\text{R})$
- (c) $\text{J/(gmol)}(\text{K})$

PROBLEM 7 (20%)

A rock containing 100% BaSO_4 is burned with coke (94% C, 6% ash) and the composition of the product is BaSO_4 (11.1%) BaS (72.9%), C (13.9%, ash (2.2%). The reaction is



Calculate the percent excess reactant, and the degree of completion of the reaction.

PROBLEM 8 (20%)

A gas cylinder to which is attached an Bourden gage appears to be at a pressure of 27.38 in. Hg at 70°F . the barometer reads 101.8 kPa. A student claims that the pressure in the tank is 1.3 psia, but another student points out that this is impossible - the pressure is really 28.2 psia. Can 1.3 psia be correct? Explain and show calculations to back up your explanation.

EXAM NO. 2
(Open Book, 2 hours)

PROBLEM 1 (25%)

A chemist attempts to prepare some very pure crystals of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ by dissolving 200 g of Na_2SO_4 (MolWt=142.05) in 400 g of boiling water. He then carefully cools the solution slowly until some $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ crystallizes out. Calculate the g of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ recovered in the crystals per 100 g of initial solution, if the residual solution after the crystals are removed contains 28% Na_2SO_4 .

Right answer but: -10 if answer is in g
of Na_2SO_4 and not g
of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$

-10 if answer not
per 100 g of initial
soln

PROBLEM 2 (25%)

Water pollution in the Hudson River has claimed considerable recent attention, especially pollution from sewage outlets and industrial wastes. To determine accurately how much effluent enters the river is quite difficult because to catch and weigh the material is impossible, weirs are hard to construct, etc. One suggestion which had been offered is to add a trace Br^- ion to a given sewage stream, let it mix well, and sample the sewage stream after it mixes well.

On one test of the proposal you add ten pounds of NaBr per hour for 24 hours to a sewage stream with essentially no Br^- in it. Somewhat downstream of the introduction point a sampling of the sewage stream shows 0.012% NaBr . The sewage density is 60.3 lb/ft^3 and river water density is 62.4 lb/ft^3 .

What is the flow rate of the sewage in lb/min ?

-10 if answer based on 0.012 fraction and not 0.00012.

-15 if 24 hr basis was used and then not converted back to per hour basis.

PROBLEM 3 (25%)

In preparing 5.00 moles of a mixture of three gases (SO_2 , H_2S , and CS_2), gases from three tanks are combined into a fourth tank. The tanks have the following compositions (mole fractions):

Gas	Tank 1	Tank 2	Tank 3	Tank 4
SO_2	0.10	0.20	0.25	0.20
H_2S	0.40	0.20	0.25	0.26
CS_2	0.50	0.60	0.50	0.54

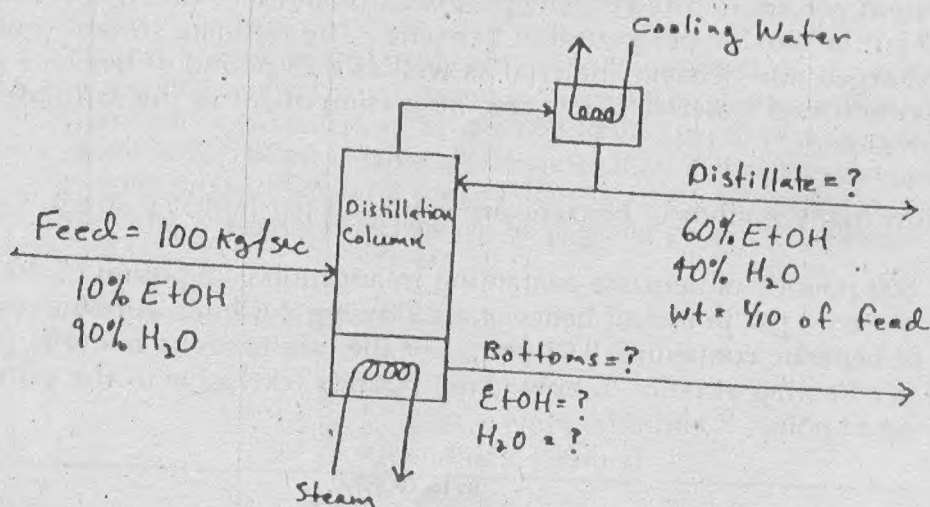
How much of Tanks 1, 2, and 3 must be mixed to give a product with composition of Tank 4?

-10 for correct answer but wrong basis

-15 A lot of people said no soln. They used wrong basis, etc. No soln but correct mat'l balance

PROBLEM 4 (25%)

- 10% a) For the given distillation process, calculate the composition of the bottoms stream.
- 15% b) If steam leaked into the column at 1000 mole/sec and all else was constant, what would the new bottoms composition be?
-5 (should be g-mole). if assumed to k-mole and not stated.



Exam No. 3
(Open Book Exam, 2 hours)

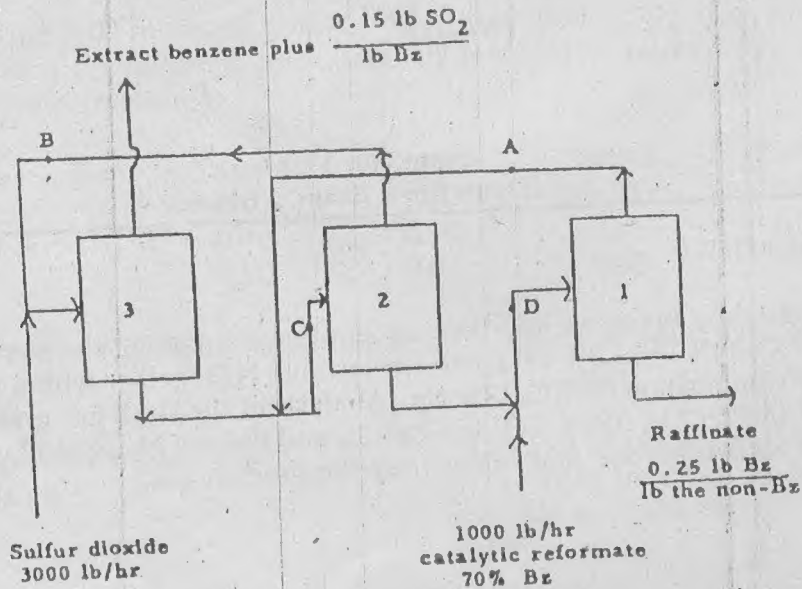
PROBLEM 1 (35%)

A company burns an intermediate product gas having the composition 4.3% CO₂, 27% CO, 10% H₂, 1.0% CH₄, and the residual N₂ together with a waste oil having the composition 87% C, 13% H₂. Analysis of the stack gas gives an Orsat analysis of 14.6% CO₂, 0.76% CO, and 7.65% O₂ and the rest N₂. Calculate the fraction of the total carbon burned that comes from the product gas.

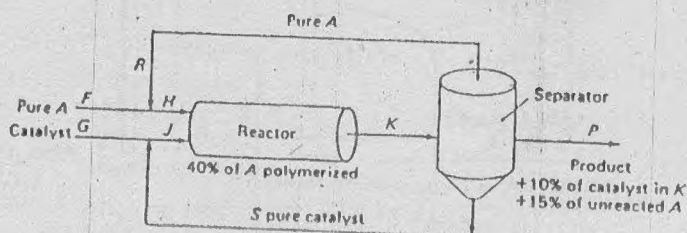
PROBLEM 2 (35%)

Benzene, toluene and other aromatic compounds can be recovered by solvent extraction with sulfur dioxide. As an example, a catalytic reformate stream containing 70% by weight benzene and 30% non-benzene material is passed through the counter-current extractive recovery scheme shown in the diagram below. One thousand pounds of the reformate stream and 3000 pounds of sulfur dioxide are fed to the system per hour. The benzene product stream (the extract) contains 0.15 pound of sulfur dioxide per pound of benzene. The raffinate stream contains all the initially charged non-benzene material as well as 0.25 pound of benzene per pound of the non-benzene material. The remaining component in the raffinate stream is the sulfur dioxide.

- (a) How many pounds of benzene are extracted per hour, i.e. are in the extract?
- (b) If 800 pounds of benzene containing in addition 0.25 pound of the non-benzene material per pound of benzene are flowing per hour at point A and 700 pounds of benzene containing 0.07 pound of the non-benzene material per pound of benzene are flowing at point B, how many pounds (exclusive of the sulfur dioxide) are flowing at points C and D?



PROBLEM 3 (30%)



Reactant A is polymerized as shown in the figure. It is mixed with fresh catalyst and recycled catalyst. Conversion of A is 40% on one pass through the reactor. Fresh catalyst (G) enters at the rate of 0.40 lb G per lb of A in stream H. The separator removes 90% of the catalyst and recycles it as well as recycling unreacted A. Nevertheless, the product stream P constraints 15% of the unreacted A and 10% of the catalyst exiting in stream K as well as the polymer product. Determine the ratio of stream R to G.

Note: catalyst does not react in the process!

Exam No. 4
(Open Book, 2 hours)

PROBLEM 1 (25%)

In the vapor-recompression evaporator (not insulated) shown in the figure below, the vapors produced on evaporation are compressed to a higher pressure and passed through the heating coil to provide the energy for evaporation. The steam entering the compressor is 98% quality at 10 psia, the steam leaving the compressor is at 50 psia and 400°F, and 6 Btu of heat are lost from the compressor per pound of steam throughput. The condensate leaving the heating coil is at 50 psia, 200°F. The replacement liquid is at the temperature of the liquid inside the evaporator.

Computer:

- the work in Btu needed for compression per pound of H_2O going through the compressor.
- the Btu of heat transferred from the heating coil to the liquid in the evaporator per pound of H_2O through the coil.
- Bonus of 5 points for correct answer to the question: What is the total heat gained or lost by the entire system.

- (b) You can find the enthalpy change at constant pressure of a Substance such as CO_2 from the solid to the gaseous state by integrating

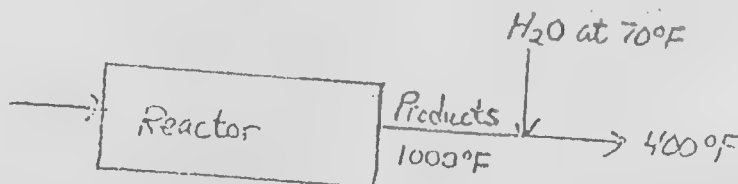
$\int_{T_1}^{T_2} C_p dT$ from T_1 (solid temperature) to T_2 (gas temperature) for a constant pressure path.

- (c) The enthalpy change of a substance can never be negative.
 (d) Heat and work are the only methods of energy transfer in a non-flow process.
 (e) Both Q and ΔH can be classed as state functions (variables)

PROBLEM 5 (25%)

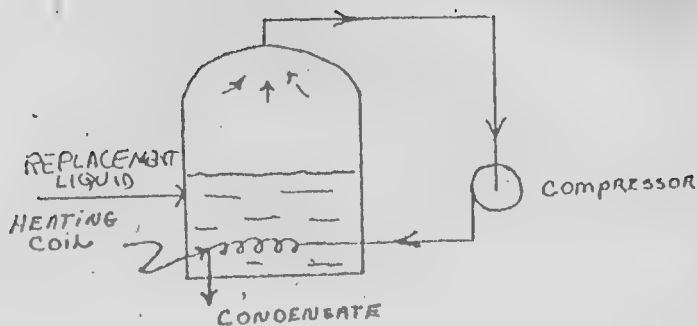
Hot reaction products (assume they have the same properties as air) at 1000°F leave a reactor. In order to prevent further reaction, the process is designed to reduce the temperature of the products to 400°F by immediately spraying liquid water into the gas stream.

How many lb of water at 70°F are required per 100 lb of products leaving at 400°F ?



For this problem you do not have to get a numerical solution. Instead list the following in this order.

1. State what the system you select is.
2. Specify open or closed.
3. Draw a picture.
4. Put all the known or calculated data on the picture in the proper places.
5. Write down the material and energy balances (use the symbols in the text) and simplify them as much as possible, list each assumption in so doing.
6. Insert the known data into the simplified equation(s) you would use to solve the problem.



PROBLEM 2 (25%)

An insulated, sealed tank that is 2 ft^3 in volume holds 8 lb of water at 100°F . A $1/4 \text{ hp}$ stirrer mixes the water for 1 hour. What is the fraction vapor at the end of the hour? Assume all the energy from the motor enters the tank.

For this problem you do not have to get a numerical solution. Instead list the following in this order:

1. State what the system you select is.
2. Specify open or closed.
3. Draw a picture.
4. Put all the known or calculated data on the picture in the proper place.
5. Write down the energy balance (use the symbols in the text) and simplify it as much as possible. List each assumption in so doing.
6. Calculate W .
7. Lists the equations with data introduced that you would use to solve the problem.
8. Explain step by step how to solve the problem (but do not do so).

PROBLEM 3 (15%)

What is the enthalpy change in Btu when 1 pound mole of air is cooled from 600°F to 100°F at atmospheric pressure.

Compute your answer by two ways:

- 1) Use the tables of the combustion gases.
- 2) Use the heat capacity equation for air.

PROBLEM 4 (10%)

Answer the following questions by placing T for true and F for false on your answer page. Grading: +2 if correct, 0 if blank, -1 if wrong.

- (a) Heat and thermal energy are synonymous terms used to express one type of energy.

Exam No. 5
(Open Book, 2 hours)

PROBLEM 1 (10%)

Answer the following questions briefly (no more than 3 sentences);

- a. Does the addition of an inert diluent to the reactants entering an exothermic process increase, decrease, or make no change in the heat transfer to or from the process?
- b. If the reaction in a process is incomplete, what is the effect on the value of the standard heat of reaction? Does it go up, down, or remain the same?
- c. How many properties are needed to fix the state of a gas so that all of the other properties can be determined?
- d. Consider the reaction $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g})$.
Is the heat of reaction with the reactants entering and the products leaving at 500K higher, lower, or the same as the standard heat of reaction?

PROBLEM 2 (10%)

Explain how you would calculate the adiabatic reaction temperature for Problem 5 below if the outlet temperature is not specified. List each step. (You can cite some of the steps listed in Problem 5 if you list them by number in Problem 5.)

PROBLEM 3 (20%)

A flue gas at 750°F and 1 atm of composition 14.0% CO₂, 1.0% CO, 6.4% O₂, and the balance N₂ is the product of combustion with excess air at 750°F and 1 atm that is used to burn coke (C).

- a. What is the volume in ft³ of the flue gas leaving the furnace per pound of carbon burned?
- b. What is the volume of air in ft³ entering the furnace per pound of C burned?

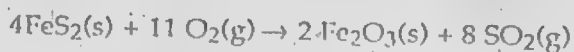
PROBLEM 4 (20%)

Seven pounds of N₂ are stored in a cylinder 0.75 ft³ volume at 120°F. Calculate the pressure in the cylinder in atmosphere:

- a. Assuming N₂ to be an ideal gas.
- b. Assuming N₂ is a real gas and using compressibility factors.

PROBLEM 5 (40%—one half each for the material and energy balances)

Pyrites (FeS_2) is converted to sulfur dioxide (SO_2) gas according to the reaction



The air which is 35% excess (based on the above reaction) for combustion enters at 27°C , the ore at 18°C , and the products leave at 900K . Because of equipment degradation, unburned FeS_2 exits from the process. In one hour 8000 kg of pyrites are fed to the process, and 2000 kg of Fe_2O_3 are produced. What is the heat added or removed from the process? Data: For FeS_2 , $C_p = 44.77 + 5.590 \times 10^{-2}T$ where T is in Kelvin and C_p is in $\text{J}/(\text{g mol})(\text{K})$. For Fe_2O_3 , $C_p = 103.4 + 6.71 \times 10^{-2}T$ with the same units.

Exam No. 6
(Open Book, 2 hours)

PROBLEM 1 (20%)

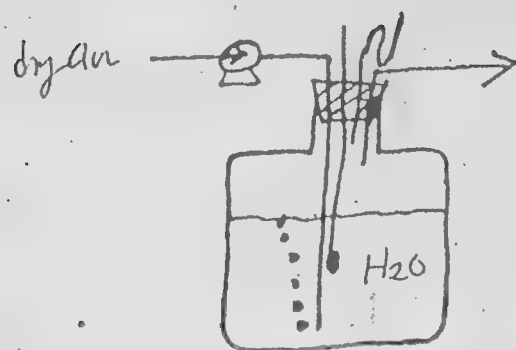
A high pressure line carries natural gas (all methane) at $10,000 \text{ kPa}$ and 40°C . How would you calculate the volume of the gas under these conditions that is equivalent to 0.03 m^3 of CH_4 at standard conditions using an equation of state? Select one equation other than van der Waal's equation, and list it on your solution page. Give a list of steps to complete the calculations. Include all the proper equations, and include a list of data involved, but you do not have to obtain a solution for the volume.

PROBLEM 2 (20%)

From the following data estimate the vapor pressure of sulfur dioxide at 100°C .

Temperature ($^\circ\text{C}$)	-10	6.3	32.1	55.5
Vapor pressure (atm)	1	2	5	10

PROBLEM 3 (20%)



Dry atmospheric air at the ambient conditions of 90°F and 29.42 in. Hg absolute passes through a small blower and is bubbled up through water so that the air leaving the water is saturated. The temperature of the water is constant at 80°F , and because of the back pressure in the system, the pressure in the vapor space in the top of the bottle is 2.7 in.

H_2O greater than atmospheric pressure. The bottle is weighed after the air is blown for 2 hours, 13 minutes, 47 seconds, and the decrease in weight was found to be 8.73 lb. What was the hourly rate of flow of air at ambient conditions in ft^3 ?

PROBLEM 4 (20%)

A vessel with a volume of 2.83 m^3 contains a mixture of nitrogen and acetone at 44.0°C and 100.0 kPa . The dew point of the mixture is 20.0°C and the relative saturation of the acetone in the mixture is 58.39% . The vapor pressure of acetone at 44.0°C is 65.35 kPa and it is 24.62 kPa at 20.0°C .

- What is the partial pressure of acetone vapor in the original mixture, in kPa ?
- How many kg moles of acetone does the original mixture contain?
- If the nitrogen-acetone mixture is cooled with the volume remaining at 2.83 m^3 constant so that 27.0% of the acetone condenses, what is the final temperature of the mixture in $^{\circ}\text{C}$?

PROBLEM 5 (20%)

A wet sludge contains 50% water by weight. This sludge is first centrifuged, and 0.1 kilograms of water are removed per kilogram of wet sludge feed. The sludge is dried further using air so that the final product contains 10% percent by weight water. The air for drying is heated, passed into an oven drier, and vented back into the atmosphere. On a day when atmospheric pressure is 760 mm Hg , the temperature is 70°F and the relative humidity is 50% , calculate the cubic meters of wet air required to dry one kilogram of sludge fed to the process. The air vented from the oven drier is at 100°F and 780 mm Hg . It has a dew point of 94°F .

1.1 a. Basis: 1 mi³

$$\frac{1 \text{ mi}^3}{1} \left| \left(\frac{5280 \text{ ft}}{1 \text{ mi}} \right)^3 \right| \left| \left(\frac{12 \text{ in}}{1 \text{ ft}} \right)^3 \right| \left| \left(\frac{2.54 \text{ cm}}{1 \text{ in}} \right)^3 \right| \left| \left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^3 \right| = \boxed{4.17 \times 10^9 \text{ m}^3}$$

b. Basis: 1 ft³/s

$$\frac{1 \text{ ft}^3}{1 \text{ s}} \left| \frac{60 \text{ s}}{1 \text{ min}} \right| \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| = \boxed{449 \text{ gal/min}}$$

1.2

$$\frac{20.0 \text{ g}}{(\text{m})(\text{s})} \left| \frac{1 \text{ lb}_m}{453.6 \text{ g}} \right| \left| \frac{0.3048 \text{ m}}{1 \text{ ft}} \right| \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left| \frac{1(\text{lb}_r)(\text{s}^2)}{32.174(\text{lb}_m)(\text{ft})} \right| \left| \frac{1(\text{hr})^2}{(3600)^2 \text{ s}^2} \right|$$

$$= \boxed{1.16 \times 10^7 \frac{(\text{lb}_r)(\text{hr})}{\text{ft}^2}}$$

1.3

$$k = \frac{g_c D_p^2}{32} \left(\frac{\text{Re}}{f} \right)$$

$$\text{a. } \left| \frac{32.2(\text{ft})(\text{lb}_m)}{32(\text{lb}_r)(\text{s}^2)} \right| \left| \frac{\text{ft}^2}{1} \right| = \boxed{\frac{(\text{lb}_m)(\text{ft}^3)}{(\text{lb}_r)(\text{s}^2)}}$$

$$\text{b. } \boxed{\text{m}^2}$$

1.4

$$\text{a. } Z = 1 + \rho B + \rho^2 C + \rho^3 D$$

Units

B	$\text{cm}^3 / \text{gmol}$
C	$(\text{cm}^3 / \text{gmol})^2$
D	$(\text{cm}^3 / \text{gmol})^3$

$$\text{b. } Z = 1 + \rho^* B^* + (\rho^*)^2 C^* + (\rho^*)^3 D^*$$

(continued)

B	$\text{ft}^3 / \text{lb}_m$
C	$(\text{ft}^3 / \text{lb}_m)^2$
D	$(\text{ft}^3 / \text{lb}_m)^3$

Let MW = mol.wt of the compound or mixture

$$B^* = B \left| \frac{\rho \text{ g mol}}{\text{cm}^3} \right| \left| \frac{1 \text{ ft}^3}{\rho^* \text{ lb}_m} \right| \left(\frac{100 \text{ cm}^2}{1 \text{ m}} \right) \left| \frac{1 \text{ m}^3}{35.31 \text{ ft}^3} \right| \left| \frac{1 \text{ lb}_m}{454 \text{ g}} \right| \frac{\text{MW g}}{1 \text{ g mol}} = \boxed{(62.38)(\text{MW})B}$$

$$C^* = C \left| \left(\frac{\rho \text{ g mol}}{\text{cm}^3} \right) \right| \left(\frac{1 \text{ ft}^3}{\rho^* \text{ lb}_m} \right)^2 \left| \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^4 \right| \left(\frac{1 \text{ m}^3}{35.31 \text{ ft}^3} \right)^2 \left| \left(\frac{1 \text{ lb}_m}{454 \text{ g}} \right)^2 \right| \left(\frac{\text{MW g}}{1 \text{ g mol}} \right)^2$$

$$= \boxed{(3891)(\text{MW})^2 C}$$

$$D^* = \boxed{2.427 \times 10^5 (\text{MW}^3) D}$$

- 1.5 The Pascal is a pressure unit, defined as 1 N/m^2 and it is not the same as a mass flux unit. The correct equivalent is $3.9 \text{ Mg/(h)(m}^2\text{)}$. If the "lb" means "lb_f," then the conversion is correct. Since the English short ton is not part of SI, "L/ton" is not, either. Correct is "34 gal/ton (142 L/Mg)."

If the ton is a metric ton, then $\boxed{129 \text{ L / ton is correct.}}$

1.6

a.
$$\frac{0.04 \text{ g}}{(\text{min})(\text{m}^3)} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \left| \frac{(12 \text{ in})^3}{1 \text{ ft}^3} \right| \left| \frac{1 \text{ lb}_m}{454 \text{ g}} \right| = \boxed{9.14 \frac{\text{lb}_m}{(\text{hr})(\text{ft}^3)}}$$

b.
$$\frac{2 \text{ L}}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left| \frac{24 \text{ hr}}{1 \text{ day}} \right| \left| \frac{1 \text{ ft}^3}{28.32 \text{ L}} \right| = \boxed{6.1 \times 10^3 \frac{\text{ft}^3}{\text{day}}}$$

c.
$$\frac{6 (\text{in.})(\text{cm}^2)}{(\text{yr})(\text{s})(\text{lb}_m)(\text{ft}^2)} \left| \frac{1 \text{ ft}^2}{(12 \text{ in})^2} \right| \left| \frac{(1 \text{ in})^2}{(2.54 \text{ cm})^2} \right| \left| \frac{1 \text{ yr}}{365 \text{ days}} \right| \left| \frac{1 \text{ day}}{24 \text{ hr}} \right| \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| \left| \frac{2}{1} \right|$$

(continued)

$$\frac{1 \text{ ft}}{12 \text{ in}} \left| \frac{0.3048 \text{ m}}{1 \text{ ft}} \right| = \boxed{1.14 \times 10^{-11} \frac{\text{m}}{(\text{kg})(\text{s}^2)}}$$

1.7 Basis: 1.0

$$\frac{1.0 \text{ Btu}}{(\text{hr})(\text{ft}^2)\left(\frac{^\circ\text{F}}{\text{ft}}\right)} \left| \frac{24 \text{ hrs}}{1 \text{ day}} \right| \left| \frac{1 \text{ ft}^2}{(12 \text{ in})^2} \right| \left| \frac{1 \text{ in}^2}{(2.54 \text{ cm})^2} \right| \left| \frac{(100 \text{ cm}^2)}{1 \text{ m}^2} \right| \left| \frac{1.8^\circ\text{F}}{1^\circ\text{C}} \right| \left| \frac{2.54 \text{ cm}}{\text{in}} \right|$$

$$\frac{253 \text{ cal}}{1 \text{ Btu}} \left| \frac{12 \text{ in}}{1 \text{ ft}} \right| \left| \frac{4.184 \text{ J}}{1 \text{ cal}} \right| \left| \frac{1 \text{ kJ}}{1000 \text{ J}} \right| = \boxed{1.49 \times 10^4 \frac{\text{kJ}}{(\text{day})(\text{m}^2)(^\circ\text{C}/\text{cm})}}$$

1.8 Basis: 1 lb H₂O

$$\text{a. } K = \frac{1}{2}mv^2 = \frac{1}{2} \left| \frac{1 \text{ lb}_m}{1} \right| \left| \left(\frac{3 \text{ ft}}{\text{s}} \right)^2 \right| \left| \frac{(\text{s}^2)(\text{lb}_r)}{32.174(\text{ft})(\text{lb}_m)} \right| = 0.14(\text{ft})(\text{lb}_r)$$

b. Let A = area of the pipe and v = water velocity. The flow rate is

$$q = Av = \left(\frac{\pi D^2}{4} \right) (v)$$

$$= \frac{\pi}{4} \left| \frac{(2 \text{ in})^2}{(12 \text{ in})^2} \right| \left| \frac{(1 \text{ ft})^2}{\text{S}} \right| \left| \frac{3 \text{ ft}}{\text{S}} \right| \left| \frac{60 \text{ S}}{1 \text{ min}} \right| \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| = \boxed{29.37 \text{ gal/min}}$$

1.9 Not really – but people do not usually distinguish between mass and weight.

1.10

- | | |
|-----|------------------------|
| (a) | N/mm or nm (nanometer) |
| (b) | C/M/S |
| (c) | 100 kPa |
| (d) | 2.73.15 k |
| (e) | 1.50m, 45 kg |
| (f) | 20°C or 28°C |
| (g) | J/s |
| (h) | 250 N |

$$1.11 \quad \frac{20 \text{ hp}}{1 \text{ hp}} \left| \frac{0.7457 \text{ kW}}{1 \text{ hp}} \right| = \boxed{14.91 \text{ kW}}$$

No, not enough power even at 100% efficiency; $68 \text{ kW} = 91.2 \text{ hp}$.

1.12 97% caffeine free probably means the coffee has only 3% of the original caffeine. However, the original caffeine is only a small fraction of the coffee so that 0.14% caffeine is entirely possible.

$$1.13 \quad \frac{1 \text{ hr}}{525 \text{ mile}} \left| \frac{2200 \text{ gal}}{1 \text{ hr}} \right| \left| \frac{1000 \text{ mile}}{1 \text{ hr}} \right| = \boxed{4190.5 \text{ gal}}$$

$$\frac{1 \text{ hr}}{475 \text{ mile}} \left| \frac{2000 \text{ gal}}{1 \text{ hr}} \right| \left| \frac{1000 \text{ mile}}{1 \text{ hr}} \right| = \frac{4190.5 \text{ gal}}{(20 \text{ gal})}$$

None: 20 gal more are needed.

$$1.14 \quad T_k = \frac{T_{\circ F} - 32}{1.8} + 273.15$$

$$C_p \left(\frac{\text{Btu}}{(\text{lb mol})(^{\circ}\text{F})} \right) = [6.945 + 10.01 \times 10^{-3} T_k - 2.794 \times 10^{-6} T_k^2]$$

$$(\text{cal}) / (\text{g mol})(\text{K}) \times \frac{1 \text{ Btu}}{252 \text{ cal}} \left| \frac{454 \text{ gmol}}{1 \text{ lbmol}} \right| \left| \frac{\text{K}}{(1.8)^{\circ}\text{F}} \right|$$

and insert $T_k = f(T_{\circ F})$ in the equation

$$T_k = \frac{T_{\circ F} - 32}{1.8} + 273.15$$

1.15 The object has a mass of 21.3 kg (within a precision of $\pm .1 \text{ kg}$). The weight is the force used to support the mass.

1.16 In American Engineering System

$$\begin{aligned} \text{Power} &= FV \\ &= \frac{800 \text{ lb}_f}{1} \left| \frac{300 \text{ ft}}{\text{min}} \right| = \boxed{2.4 \times 10^5 \frac{(\text{lb}_f)(\text{ft})}{\text{min}}} \end{aligned}$$

In SI

$$\begin{aligned} \text{Power} &= \frac{4000 \text{ N}}{1} \left| \frac{1.5 \text{ m}}{\text{s}} \right| \frac{1 \text{ watt}}{1(\text{N})(\text{M})/\text{s}} \\ &= \boxed{6000 \text{ watts}} \end{aligned}$$

$$1.17 \quad K = \frac{1}{2} m v^2$$

$$\begin{aligned} &= \frac{1}{2} \left| \frac{2300 \text{ kg}}{1} \right| \left| \frac{1 \text{ lb}_m}{0.454 \text{ kg}} \right| \left| \frac{(10.0 \text{ ft})^2}{\text{s}^2} \right| \left| \frac{1}{32.2 \text{ lb}_m \left| \frac{\text{ft}}{\text{sec}^2} \right|} \right| \left| \frac{1 \text{ Btu}}{778.2(\text{ft})(\text{lb}_f)} \right| \\ &= \boxed{10.11 \text{ Btu}} \end{aligned}$$

1.18 Basis: 10 tons at 6 ft/s

$$K = \frac{1}{2} m v^2 = \frac{1}{2} \left| \frac{20,000 \text{ lb}_m}{1} \right| \left| \frac{(6 \text{ ft})^2}{\text{s}^2} \right| \frac{1(\text{s}^2)(\text{lb}_f)}{32.2(\text{ft})(\text{lb}_m)} = \boxed{11,200(\text{ft})(\text{lb}_f)}$$

1.19

$$u = k \left[\frac{\tau}{\rho} \right]^{1/2} \quad \text{in SI units} \quad \frac{\tau [N/m^2]}{\rho [kg/m^3]} \left[\frac{(N)(m)}{kg} \right]^{1/2}$$

$$u' \left[\frac{\text{ft}}{\text{s}} \right] = k \left[\right] \left\{ \left[\frac{\tau' [\text{lb}_f/\text{ft}^2]}{\rho' [\text{lb}_m/\text{ft}^3]} \right] \frac{1.356 \text{ J}}{1(\text{lb}_f)(\text{ft})} \right\}$$

$$\frac{1(N)(m)}{1(J)} \left| \frac{1 \text{ lb}_m}{0.4536 \text{ kg}} \right\}^{1/2} \frac{3.2808 \text{ ft}}{1 \text{ m}}$$

(continued)

Note: $\frac{(N)(m)}{(kg)} \left| \frac{1(kg)(m)}{(1N)s^2} \right| = \bigcirc = \frac{m^2}{s^2}$ so that k is a dimensionless coefficient

$$u' = k(5.672) \left[\frac{\tau'}{\rho'} \right]^{1/2}$$

1.20 Insert the units in both sides of the equation

$$\frac{\text{bbl}}{\text{yr}} \cdot \frac{24}{1000} \left(\frac{\text{psia}}{\text{psia}} \right)^{0.68} \left| \frac{\text{ft}^{1.73}}{\text{ft}^{0.50}} \right| \left| \frac{\text{ft}^{0.51}}{\text{ft}^{0.51}} \right|$$

$$\frac{\text{bbl}}{\text{yr}} \neq \text{ft}^{2.74} \text{ assuming } F_p \text{ and } C \text{ are dimensionless}$$

To be consistent, the coefficient $24/1000$ must have the following units:

$$\frac{1 \text{ bbl}}{\text{yr}} \left| \frac{42 \text{ gal}}{1 \text{ bbl}} \right| \left| \frac{0.133 \text{ ft}^3}{1 \text{ gal}} \right|$$

$$= 5.59 \frac{\text{ft}^3}{\text{yr}} \text{ on the left hand side so the coefficient must multiply } \text{ft}^{2.74} \text{ to get}$$

$$\text{ft}^3/\text{yr} \text{ or } \left[\text{multiply by } \frac{\text{ft}^{0.26}}{\text{yr}} \right]$$

1.21 The left handside has the units of $(\text{length})^{-1}$ and x/a is dimensionless so that the third answer is correct.

1.22 The inside diameter of the tubing is $6.35 - 290.762) = 4.826 \text{ mm}$

$$\text{The flow area is } \frac{\pi}{4} (4.826)^2 \text{ mm}^2 = \frac{(18.292) \text{ mm}^2}{(100) \text{ mm}^2 / \text{cm}^2} = 0.1829 \text{ cm}^2$$

The velocity of the sample gas is

$$(10) \frac{\text{cm}^3}{\text{s}} \left| \frac{1}{(0.1829) \text{ cm}^2} \right| = 54.67 \frac{\text{cm}}{\text{s}}$$

(continued)

For a travel distance of 125 ft, the time required for the flow is

$$\frac{(125)\text{ft}}{(54.67)\frac{\text{cm}}{\text{s}}} \left| \frac{(30.38)\text{cm}}{\text{ft}} \right| = \boxed{69.69 \text{ seconds}}$$

Including the 5-sec instrument delay, about 75 sec will be required for sampling. A delay time of 75 sec may be acceptable for low leak rates, but faster detection would be desired for dangerous concentrations of toxic gases.

- b) To reduce sampling time:
- 1) Increase the flow rate for same diameter tubing,
 - 2) Decrease the tubing diameter for same flow rate,
 - 3) Reduce the tubing length.

- 1.23 Place units for the symbols in the given equation, and equate the units on the left and right hand sides of the equation by assigning appropriate units to the coefficient 0.943.

$$\begin{array}{ccc} \text{LHS} & & \text{RHS} \\ \frac{\text{Btu}}{(\text{hr})(\text{ft}^2)(\Delta^\circ\text{F})} \cdot \left[\left(\frac{\text{Btu}}{(\text{hr})(\text{ft})(\Delta^\circ\text{F})} \right)^3 \left(\frac{\text{lb}_m}{\text{ft}^2} \right)^2 \left| \frac{\text{ft}}{(\text{hr})^2} \right| \left| \frac{\text{Btu}}{\text{lb}_m \text{ ft}} \right| \left| \frac{(\text{hr})(\text{ft})}{\text{lb}_m} \right| \left| \frac{1}{\Delta^\circ\text{F}} \right| \right]^{1/4} \end{array}$$

The units are the same on the right and left so that 0.943 has no units associated with it.

- 1.24 The equation is dimensionally consistent. Use the SI System to show

$$\left[\frac{2\text{N}|\text{cm}^3|(\text{g})(\text{cm})}{\text{m}^2|\text{g}|(1\text{N})(\text{s}^2)} \right]^{1/2} \rightarrow \frac{\text{cm}^2}{(\text{m})(\text{s})} \rightarrow \frac{\text{m}}{\text{s}}, \text{ the units of } v$$

$$\frac{2|15 \text{ mmHg}|1.013 \times 10^5 \text{ Pa}|\frac{1\text{N}}{\text{m}^2}|10^5(\text{g})(\text{cm})|(\text{cm}^3)|}{760 \text{ mmHg}|1 \text{ Pa}|\underbrace{(1\text{N})(\text{s}^2)}_{\text{kgm}}|1.20 \text{ g}|\left(\frac{1\text{m}}{100 \text{ cm}}\right)^2}$$

$$= \left[\frac{33322.4 \text{ cm}^2}{\text{s}^2} \right]^{1/2}$$

(continued)

$$\frac{(33322.4)^{1/2} \text{ cm}}{\text{s}} \left| \frac{1 \text{ in}}{2.54 \text{ cm}} \right| \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| = 5.989 \text{ ft/s}$$

1.25 Introduce the units. The net units are the same on both sides of the equation.

$$\boxed{(\text{ft})(\text{ft})^{1.5} \left(\frac{\text{ft}}{\text{s}^2} \right)^{1/2} = \frac{\text{ft}^3}{\text{s}}}$$

1.26 a. Yes. b. The dimensions are those of $k_x/u^{0.487}$, or

$$\frac{(\text{moles})}{(\text{cm})^2 (\text{s})} \left(\frac{\text{s}}{\text{cm}} \right)^{0.487} \rightarrow \boxed{\frac{(\text{moles})}{(\text{cm})^{2.487} (\text{s})^{0.513}}}$$

c. K' has the units $\rightarrow \boxed{\frac{\text{moles}}{(\text{cm}^2)(\text{sec})} \left(\frac{\text{sec}}{\text{ft}} \right)^{0.487}}$

1.27 Basis: $Dv\rho/\mu$

$$1. \frac{2 \text{ in}}{\text{s}} \left| \frac{10 \text{ ft}}{\text{s}} \right| \left| \frac{62.4 \text{ lb}_m}{\text{ft}^3} \right| \left| \frac{(\text{hr})(\text{ft})}{0.3 \text{ lb}_m} \right| \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| = \boxed{1.248 \times 10^6}$$

$$2. \frac{20 \text{ mi}}{\text{hr}} \left| \frac{1 \text{ lb}_m}{\text{ft}^3} \right| \left| \frac{(\text{s})(\text{ft})}{0.14 \times 10^{-4} \text{ lb}_m} \right| \left| \frac{5280 \text{ ft}}{1 \text{ mi}} \right| \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| = \boxed{2.10 \times 10^7}$$

$$3. \frac{1 \text{ ft}}{\text{s}} \left| \frac{1 \text{ m}}{\text{s}} \right| \left| \frac{12.5 \text{ kg}}{\text{m}^3} \right| \left| \frac{1}{2 \times 10^{-6} \text{ cp}} \right| \left| \frac{100 \text{ cp}}{1 \text{ p}} \right| \left| \frac{0.305 \text{ m}}{100 \text{ cm}} \right| \left| \frac{1 \text{ m}}{100 \text{ cm}} \right| \left| \frac{10^3}{1 \text{ kg}} \right| = \boxed{1.91 \times 10^9}$$

$$4. \frac{2 \text{ mm}}{\text{s}} \left| \frac{3 \text{ cm}}{\text{s}} \right| \left| \frac{25 \text{ lb}_m}{\text{ft}^3} \right| \left| \frac{1}{1 \times 10^{-6} \text{ cp}} \right| \left| \frac{100 \text{ cp}}{1 \text{ p}} \right| \left| \frac{454 \text{ g}}{\text{lb}_m} \right| \left| \frac{1 \text{ cm}}{10 \text{ mm}} \right| \left| \frac{\text{ft}^3}{(30.48)^3 \text{ cm}^3} \right| = \boxed{2.38 \times 10^7}$$

1.28 $\dot{m} = \rho Q K$

$$\dot{m} \frac{\text{ton}}{\text{hr}} = \left| \frac{\rho \text{ lb}_m}{\text{ft}^3} \right| \left| \frac{Q \text{ gal}}{\text{m}} \right| \left| \frac{K}{2000 \text{ lb}_m} \right| \left| \frac{1 \text{ ton}}{\text{gal}} \right| \left| \frac{0.1337 \text{ ft}^3}{\text{hr}} \right| \left| \frac{60 \text{ min}}{\text{hr}} \right|$$

(continued)

$$K = \frac{m \text{ ton}}{\text{hr}} \left| \frac{\text{ft}^3}{\rho \text{ lb}_m} \right| \left| \frac{\text{min}}{Q \text{ gal}} \right| = \boxed{4.011 \times 10^{-3} \frac{(\text{ton})(\text{ft}^3)(\text{min})}{(\text{lb}_m)(\text{gal})(\text{hr})}}$$

1.29

The first paragraph of the letter is ok. In the second paragraph, the author is wrong. The molecular weight, even in SI, is the ratio of mass to moles (or the mass per a fixed number of molecules) and is not dimensionless.

1.30

a) $\text{MW} = 40.08 \text{ g/g mol} + 12.01 \text{ g/mol} + 2(16.00) \text{ g/gmol}$

$$= \boxed{100.9 \text{ g/g mol CaCO}_3}$$

b) $\frac{10 \text{ g CaCO}_3}{100.09 \text{ g CaCO}_3} \left| \frac{1.0 \text{ g mol CaCO}_3}{100.09 \text{ g CaCO}_3} \right| = \boxed{0.0999 \text{ g mol}}$

c) $\frac{20 \text{ g CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| = \boxed{20.0 \text{ lb mol CaCO}_3}$

d) $\frac{2 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \left| \frac{100.09 \text{ lb CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = \boxed{90,880 \text{ g CaCO}_3}$

1.31

A mole is a number of molecules. Molecular weight is the mass per mole.

1.32

All of the answers are wrong. A mole is a number of molecules.

- a) It is not a number of molecules in a volume
- b) It is not a weight
- c) It is not a number of molecules in a gram
- d) It is not an atomic weight or sum thereof
- e) It is not a molecular weight

1.33.

a) $\frac{4 \text{ g mol mg Cl}_2}{\text{gmol MgCl}_2} \left| \frac{(95.23) \text{ g MgCl}_2}{\text{gmol MgCl}_2} \right| = \boxed{380.9 \text{ g}}$

b) $\frac{2 \text{ lb mol C}_3\text{H}_8}{\text{lb mol C}_3\text{H}_8} \left| \frac{(44.09) \text{ lb C}_3\text{H}_8}{\text{lb mol C}_3\text{H}_8} \right| \left| \frac{454 \text{ g C}_3\text{H}_8}{1 \text{ lb C}_3\text{H}_8} \right| = \boxed{4 \times 10^4 \text{ g C}_3\text{H}_8}$

c) $\frac{16 \text{ g N}_2}{(28.02) \text{ g N}_2} \left| \frac{\text{gmol N}_2}{(28.02) \text{ g N}_2} \right| \left| \frac{1 \text{ lb mol N}_2}{454 \text{ gmol N}_2} \right| = \boxed{0.987 \text{ lb mol N}_2}$

(continued)

$$d) \frac{3 \text{ lb } C_2H_6O}{(46.07) \text{ lb } C_2H_6O} \left| \frac{1 \text{ lb mol } C_2H_6O}{1 \text{ lb } C_2H_6O} \right| \frac{(454) \text{ g mol } C_2H_6O}{1 \text{ lb } C_2H_6O}$$

$$= \boxed{29.56 \text{ gmol } C_2H_6O}$$

1.34 The statement is partially correct. A mole is a number of entities, not a quantity of material. "Quantity" usually is not considered to be enumerated.

1.35 a) mol^{-1} means the inverse of the unit "mol."

b) Yes.

1.36 Basis: 100 g of the compound

comp.	g	MW	gmol	Ratio of Atoms
C	42.11	12	3.51	1.09
O	51.46	16	3.22	1
H	6.43	1.008	6.38	2
			13.11	

Multiply by 11 to convert the ratios into integers

$\therefore$ The formula becomes $C_{12}O_{11}H_{22}$

Checking MW: $12(12) + 11(16) + 22(1.008) = 342$ (close enough)

1.37 Vitamin A, Mol Wt.: 286 Vitamin C, mol. wt: 176

C	H	O	C	H	O	C	H	O	C	H	O
1	3		2	2		6	3	1			
1	3		3	4			1	1			
1	2		2	2		4	4	-			
1	2		3	4		-	-	-			
1	2		1	3	1	10	8	2			
3	2		-	-	-						
1	3		20	30	1						

Vitamin A: Basis is first entry in each calculation.

a. 1. $\frac{200 \text{ g mol}}{1 \text{ g mol}} \left| \frac{286 \text{ g}}{454 \text{ g}} \right| \frac{1 \text{ lb}}{1 \text{ lb}} = \boxed{1.26 \text{ lb}}$

2. $\frac{16 \text{ g}}{454 \text{ g}} \left| \frac{1 \text{ lb}}{1 \text{ lb}} \right| = \boxed{0.0352 \text{ lb}}$

(continued)

$$\begin{aligned} \text{b. } 1. \quad & \frac{1.00 \text{ lb mol}}{1 \text{ lb mol}} \left| \frac{454 \text{ g mol}}{1 \text{ g mol}} \right| \frac{286 \text{ g}}{1 \text{ g mol}} = 1.298 \times 10^5 \text{ g} \\ & = \boxed{1.298 \text{ kg}} \end{aligned}$$

$$2. \quad \frac{12 \text{ lb}}{1 \text{ lb}} \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = \boxed{5.448 \times 10^3 \text{ g}}$$

Vitamin C:

$$\text{a. } 1. \quad \frac{2.00 \text{ g mol}}{1 \text{ g mol}} \left| \frac{176 \text{ g}}{454 \text{ g}} \right| \frac{1 \text{ lb}}{1 \text{ lb}} = \boxed{0.77 \text{ lb}}$$

$$2. \quad \frac{16 \text{ g}}{454 \text{ g}} \left| \frac{1 \text{ lb}}{1 \text{ lb}} \right| = \boxed{0.0352 \text{ lb}}$$

$$\begin{aligned} \text{b. } 1. \quad & \frac{1.00 \text{ lb mol}}{1 \text{ lb mol}} \left| \frac{454 \text{ g mol}}{1 \text{ g mol}} \right| \frac{176 \text{ g}}{1 \text{ g mol}} = \boxed{7.994 \times 10^4 \text{ g}} \\ & = \boxed{79.9 \text{ kg}} \end{aligned}$$

$$2. \quad \frac{12 \text{ lb}}{1 \text{ lb}} \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = \boxed{5.448 \times 10^3 \text{ g}}$$

1.38

$$\frac{1.049 \text{ g/cm}^3 \text{ HAc}}{1.00 \text{ g/cm}^3 \text{ H}_2\text{O}} \left| \frac{1.00 \text{ g/cm}^3 \text{ H}_2\text{O}}{453.6 \text{ g}} \right| \frac{1 \text{ lb}_m}{1 \text{ lb}_m} \left(\frac{1 \text{ m}}{3.2808 \text{ ft}} \right)^3 \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 = 65.48 \text{ lb}_m/\text{ft}^3$$

or

$$\frac{1.049 \frac{\text{lb}_m}{\text{ft}^3} \text{ HAc}}{1.00 \frac{\text{lb}_m}{\text{ft}^3} \text{ H}_2\text{O}} \left| \frac{62.4 \frac{\text{lb}_m}{\text{ft}^3} \text{ H}_2\text{O}}{1 \text{ lb}_m} \right| = \boxed{65.48 \text{ lb}_m/\text{ft}^3}$$

1.39

$$\rho_{\text{oil}} = \frac{(0.82) \frac{\text{lb oil}}{\text{ft}^3 \text{ oil}}}{1 \frac{\text{lb H}_2\text{O}}{\text{ft}^3 \text{ H}_2\text{O}}} \left| \frac{62.4 \frac{\text{lb H}_2\text{O}}{\text{ft}^3 \text{ H}_2\text{O}}}{1 \text{ lb}_m} \right| = \boxed{51.168 \text{ lb/ft}^3 \text{ for the oil}}$$

1.40 Basis: 1000 lb oil

$$\frac{0.926 \frac{\text{lb oil}}{\text{ft}^3}}{1.00 \frac{\text{lb H}_2\text{O}}{\text{ft}^3}} \left| \frac{62.4 \frac{\text{lb H}_2\text{O}}{\text{ft}^3}}{1 \text{ ft}^3} \right| = 57.78 \frac{\text{lb oil}}{\text{ft}^3}$$

$$\frac{1000 \text{ lb oil}}{57.78 \text{ lb oil}} \left| \frac{1 \text{ ft}^3 \text{ oil}}{1 \text{ ft}^3} \right| \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| = 129.5 \text{ gal}$$

1.41. Basis: 1 L soln MW $\text{H}_2\text{SO}_4 = 98.08$

$$\frac{1.858 \text{ g/cm}^3 \text{ H}_2\text{SO}_4 \text{ soln}}{1.00 \text{ g/cm}^3 \text{ H}_2\text{O}} \left| \frac{1.00 \text{ g/cm}^3 \text{ H}_2\text{O}}{1 \text{ cm}^3} \right| =$$

$$1.858 \frac{\text{g H}_2\text{SO}_4}{\text{cm}^3 \text{ 96\% acid}} = \rho \text{ soln}$$

$$\text{a) } \frac{0.10 \text{ gmol H}_2\text{SO}_4}{\text{L soln}} \left| \frac{98.08 \text{ g H}_2\text{SO}_4}{1 \text{ gmol H}_2\text{SO}_4} \right| \left| \frac{1.00 \text{ g 96\% H}_2\text{SO}_4}{0.96 \text{ g H}_2\text{SO}_4} \right| = \boxed{\frac{10.22 \text{ g}}{\text{L soln}}}$$

$$\text{b) } \frac{1 \text{ cm}^3 \text{ 96\% acid}}{1.858 \text{ g H}_2\text{SO}_4} \left| \frac{10.22 \text{ g H}_2\text{SO}_4}{\text{L soln}} \right| = \boxed{5.50 \frac{\text{cm}^3}{\text{L soln}} \text{ 96\% acid}}$$

$$\text{c) Mass of 1 L soln: } 10.22 \text{ g 96\% acid} + \frac{1.00 \text{ g H}_2\text{O}}{\text{cm}^3} \left| \frac{1000 \text{ cm}^3}{\text{L}} \right| = \boxed{1004.7 \text{ g}}$$

$$\text{so } \rho_{0.1} = \frac{1004.7 \text{ g}}{1000 \text{ cm}^3} = \boxed{1.0047 \frac{\text{g}}{\text{cm}^3}}$$

$$\text{d) ppm is } \frac{\text{g H}_2\text{SO}_4}{\text{g soln}} (10^6) = \frac{9.808 \text{ g H}_2\text{SO}_4}{1004.7 \text{ g soln}} \times 10^6 = \boxed{9,760 \text{ ppm}}$$

Solutions - Chapter - 1

- 1.42 $\rho_{\text{ice}} = 0.917 \text{ g/cm}^3$ Density of ice
 $\rho_{\text{H}_2\text{O}} = 1.00 \text{ g/cm}^3$ Density of $\text{H}_2\text{O(l)}$
 $\rho_{\text{alcohol}} = 0.791 \text{ g/cm}^3$ Density of pure alcohol

If the rum is 97 proof (48.5% EtOH), the density is 0.917 g/cm^3 . As the proof rises, the density of the solutions decreases below that of ice, causing the ice to sink.

- 1.43 Basis: 1 gal. of solution.

Mass of solution:

$$\frac{1.0824 \text{ lb soln}}{\text{ft}^3 \text{ H}_2\text{O}} \left| \frac{62.4 \text{ lb H}_2\text{O}}{\text{ft}^3 \text{ H}_2\text{O}} \right| \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \left| \frac{1 \text{ gal}}{1} \right| = \boxed{9.03 \text{ lb soln}}$$

$$\text{Mass fraction KOH} = \frac{0.813 \text{ lb}}{9.03 \text{ lb}} = \boxed{0.09}$$

$$\text{Mass fraction H}_2\text{O} = 1 - 0.09 = \boxed{\frac{0.91}{1.00 \text{ Total}}}$$

- 1.44 $\rho_{\text{water at } 60^\circ\text{F}} = 0.99905 \text{ g/mL}$

$$\text{Sp. gr. of benzene at } \frac{60^\circ\text{F}}{60^\circ\text{F}} = \frac{0.879 \text{ g/cm}^3}{0.99905 \text{ g/cm}^3} = \boxed{0.879}$$

- 1.45

a.
$$\frac{0.90 \text{ kg liq.}}{\frac{\text{m}^3}{\text{kg H}_2\text{O}}} \left| \frac{10^3 \text{ kg H}_2\text{O}}{\text{m}^3} \right| = \boxed{900 \frac{\text{kg liq.}}{\text{m}^3}}$$

b.
$$\frac{1 \text{ m}^3}{900 \text{ kg liq.}} \left| \left(\frac{3.2808 \text{ ft}^3}{1 \text{ m}^3} \right)^3 \right| \frac{0.454 \text{ kg}}{1 \text{ lb}_m} = \boxed{0.0178 \frac{\text{ft}^3}{\text{lb}_m}}$$

(continued)

$$c. \quad \frac{900 \text{ kg}}{1 \text{ m}^3} \left| \frac{1 \text{ m}^3}{1000 \text{ L}} \right| \frac{1.5 \text{ L}}{1} = 1.35 \text{ kg}$$

$$0.232 + 1.35 = \boxed{1.582 \text{ kg}}$$

1.46 Basis: 1.704 kg HNO₃ 1 kg H₂O

a.	Comp.	Kg	mass fraction	weight percent
	HNO ₃	1.704	0.63	63
	H ₂ O	1	0.37	37
	Total	2.704	1.00	37

b. Ignore the change of density of water with temperature

$$\frac{0.63 \text{ lb HNO}_3}{1 \text{ lb soln}} \left| \frac{1.382 \text{ lb soln}}{1 \text{ ft}^3 \text{ soln}} \right| \frac{62.4 \text{ lb H}_2\text{O}}{1 \text{ ft}^3 \text{ H}_2\text{O}} = \boxed{\frac{54.3 \text{ lb HNO}_3}{\text{ft}^3 \text{ soln}}}$$

$$c. \quad \frac{1.382 \text{ g soln}}{1 \text{ cm}^3 \text{ soln}} \left| \frac{1.00 \text{ g H}_2\text{O}}{1 \text{ cm}^3 \text{ H}_2\text{O}} \right| \frac{0.63 \text{ g HNO}_3}{1 \text{ g soln}} \left| \frac{1 \text{ g mol HNO}_3}{63 \text{ g HNO}_3} \right| \frac{10^3 \text{ cm}^3}{1 \text{ L}} =$$

$$\boxed{\frac{13.8 \text{ g mol}}{\text{L}}}$$

1.47 Basis: 1 Day

$$\frac{200 \text{ mg HgCl}_2}{105 \text{ gal}} \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| \frac{1 \text{ ft}^3}{62.4 \text{ lb}} \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| \frac{1 \text{ gmol HgCl}_2}{271.52 \text{ g HgCl}_2}$$

$$\frac{1 \text{ g}}{10^3 \text{ mg}} \left| \frac{1 \text{ gmol Hg}}{1 \text{ gmol HgCl}_2} \right| \frac{200.61 \text{ g Hg}}{1 \text{ gmol Hg}}$$

$$= 2.90 \times 10^{-10} \frac{\text{g HgCl}_2}{\text{g soln}} = 3.90 \times 10^{-4} \text{ ppm}$$

This discharge for 1 analysis is just below the prescribed limit.

1.48

Density of acetaldehyde

$$= 783 \frac{\text{kg}}{\text{m}^3}$$

volume of acetaldehyde

$$= \frac{1130 \text{ kg}}{783 \text{ kg acetaldehyde}} \times 1 \text{ m}^3$$

$$= 0.144 \text{ m}^3$$

 $\therefore$ maximum required volume

$$= 0.144 \text{ m}^3$$

volume of vessel = max. required volume

$$= \frac{4}{3} \pi r^3$$

$$r = \sqrt[3]{\frac{3}{4\pi} \times (0.144 \text{ m}^3)}$$

$$= 0.33 \text{ m}$$

 $\therefore$ a spherical vessel with a radius of 0.33 m could be used to store the liquids.

1.49 Example: Fe in Brand A

$$\frac{1310 \text{ g Fe}}{10^6 \text{ g Total}} = \boxed{1.31 \times 10^{-3} \text{ mass fraction}}$$

The other entries are similar

1.50

$$\text{Specific gravity} = 0.792 \left(\frac{\text{g MeOH}}{\text{cm}^3} \right)$$

$$\frac{0.500 \text{ L}}{1 \text{ L}} \times \frac{1000 \text{ cm}^3}{1 \text{ L}} \times \frac{0.792 \text{ g MeOH}}{\text{cm}^3} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{16 \text{ Oz}}{1 \text{ lb}} = \boxed{13.96 \text{ Oz}}$$

1.51 Basis: 100,010 lb

$$\frac{10,010 \text{ lb}}{8.80 \text{ lb}} \times \frac{1 \text{ gal}}{8.80 \text{ lb}} \times \frac{0.134 \text{ ft}^3}{\text{gal}} = \boxed{152 \text{ ft}^3}$$

1.52 a) b)

c) Yes, because for solids and liquids the ratio in ppb is mass whereas for gases the ratio is in moles.

1.53 Basis: 5000 bbl of 28° API oil + 20,000 bbl 15° API oil → calc. ρ_{mix} in lb_m/gal , lb_m/ft^3 (assume volumes are additive); 1 bbl = 42 gal

$$\rho_{\text{mix}} = \frac{\text{lb}_m 28^\circ \text{ oil} + \text{lb}_m 15^\circ \text{ oil}}{\text{total vol}} = \frac{\text{lb}_m 28^\circ \text{ oil} + \text{lb}_m 15^\circ \text{ oil}}{5000 + 20,000 \text{ bbl}}$$

$$\text{SG}_{28^\circ} = \frac{141.5}{28 + 131.5} = 0.887 \quad \rho_{28^\circ} = (0.887)(62.4) = \boxed{55.36 \text{ lb}_m / \text{ft}^3}$$

$$\text{SG}_{15^\circ} = \frac{141.5}{15 + 131.5} = 0.966 \quad \rho_{15^\circ} = (0.966)(62.4) = 60.27 \text{ lb}_m / \text{ft}^3$$

$$V_{28^\circ} = (5000 \text{ bbl})(42 \text{ gal} / \text{bbl}) \left(\text{ft}^3 / 7.481 \text{ gal} \right) = 2.807 \times 10^4 \text{ ft}^3$$

$$V_{15^\circ} = (20,000)(42 \text{ gal} / \text{bbl}) \left(\text{ft}^3 / 7.481 \text{ gal} \right) = 1.123 \times 10^5 \text{ ft}^3$$

$$\begin{aligned} \therefore \rho_{\text{mix}} &= \frac{\left(55.36 \frac{\text{lb}_m 28^\circ}{\text{ft}^3} \right) (2.807 \times 10^4 \text{ ft}^3) + \left(60.27 \frac{\text{lb}_m 15^\circ}{\text{ft}^3} \right) (1.123 \times 10^5 \text{ ft}^3)}{2.807 \times 10^4 + 1.123 \times 10^5 \text{ ft}^3} \\ &= \boxed{59.29 \text{ lb}_m / \text{ft}^3} \\ &= \boxed{7.93 \text{ lb}_m / \text{gal}} \end{aligned}$$

1.54

$$\text{Sp. gr. } \frac{60^\circ \text{F}}{60^\circ \text{F}} = \frac{141.5}{^\circ \text{API} + 131.5} = \frac{141.5}{45.38 + 131.5} = \boxed{0.80}$$

$$\boxed{\text{Sp. gr. } \frac{60^\circ \text{F}}{60^\circ \text{F}} \neq \text{Density}}$$

1.55 Basis: 190,000 ppm

$$\frac{190,000 \text{ g PCB}}{10^6} \times 100 = \boxed{19\%}$$

1.56 Yes. Bases are first entries.

$$\text{Sample: } \frac{4,800 \text{ mol CCl}_4}{10^4 \text{ mol air}} \left| \frac{153.84 \text{ g CCl}_4}{1 \text{ g mol CCl}_4} \right| \frac{1 \text{ g mol air}}{29 \text{ g air}}$$

$$= 25.46 \times 10^{-3} \text{ mg CCl}_4 / \text{g air}$$

Standard: 1 m³ air including CCl₄ = 1 m³ air alone; at 300K and 1 atm, the density of air is 0.8497 m³/kg.

$$\frac{12.6 \text{ mg CCl}_4}{1 \text{ m}^3 \text{ air}} \left| \frac{1 \text{ m}^3 \text{ air}}{0.8497 \text{ kg air}} \right| \frac{1 \text{ kg}}{10^3 \text{ g}} = \boxed{14.83 \times 10^{-3} \text{ mg CCl}_4 / \text{g air}}$$

1.57

$$\text{a. } \frac{25,600 \text{ ton P}}{\text{yr}} \left| \frac{2.6 \text{ yr}}{1} \right| \left| \frac{1}{1.2 \times 10^{14} \text{ gal}} \right| \left| \frac{1 \text{ gal}}{3.785 \text{ L}} \right| \left| \frac{2000 \text{ lb}}{1 \text{ ton}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \left| \frac{10^6 \mu \text{ g}}{1 \text{ g}} \right|$$

$$= \boxed{133.1 \mu \text{ g/L}}$$

$$\text{b. } \frac{19,090 \text{ lb(P)municipal}}{30,100 \text{ lb(P)total}} = \boxed{63.4\%}$$

$$\text{c. } \frac{19,090 \text{ lb(P)municipal}}{30,100 \text{ lb(P)total}} \left| \frac{0.70 \text{ lb(P)det.}}{1 \text{ lb(P)municipal}} \right| \left| \frac{100 \text{ lb(P)total}}{30,100 \text{ lb(P)total}} \right| = \boxed{44.4\%}$$

For d. and e. assume that (P)_{outflow} remains unchanged.

$$\text{d. } \text{P retained/yr} = 2,240 + 6,740 + 0.7 \times 19,090 - 4,500 = 17,843 \text{ ton/yr.}$$

P conc. in ppb =

$$\frac{17,843 \text{ ton}}{\text{yr}} \left| \frac{2.6 \text{ yr}}{1} \right| \left| \frac{1}{1.2 \times 10^{14} \text{ gal}} \right| \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \left| \frac{1 \text{ g/cm}^3}{8.345 \text{ lb/gal}} \right| \left| \frac{10^9 \text{ g}}{1 \text{ billion g}} \right| = 92.6 \text{ ppb}$$

This is greater than 10 ppb. Eutrophication will not be reduced.

(continued)

Solutions - Chapter - 1

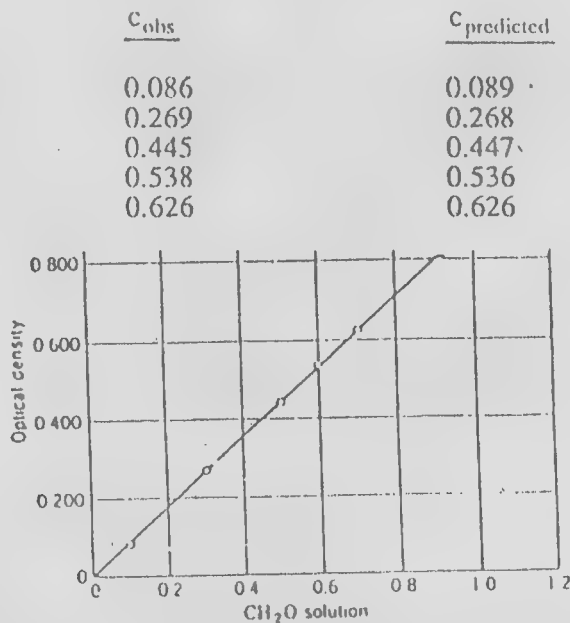
c. $P_{\text{retained/yr}} = 2,240 + 6,740 + 0.3 \times 19,090 - 4,500 = 10,207 \frac{\text{ton}}{\text{yr}}$

P conc. in ppb =

$$\frac{10,207 \text{ ton}}{\text{yr}} \times \frac{2.6 \text{ yr}}{1} \times \frac{1}{1.2 \times 10^{14} \text{ gal}} \times \frac{2000 \text{ lb}}{\text{ton}} \times \frac{1 \text{ g/cc}}{8.345 \text{ lb/gal}} \times \frac{10^9 \text{ g}}{1 \text{ billion g}} = 53.2 \text{ ppb}$$

This will not help.

1.58 $n=5; \quad \Sigma x_i^2 = 1.20; \quad \Sigma x_i y_i = 1.0728; \quad \Sigma y_i^2 = 0.959102; \quad b_0 = 0;$
 $b_1 = 1.0728 / 1.20 = 0.894$



1.59 Basis: 100 kg mol gas

Comp	kg mol	MW	Mass(kg)
N ₂	40	28	1120
CO ₂	30	44	1320
CH ₄	30	16	480
	100		2920

Average molecular weight is $\frac{2920}{100} = 29.2 \frac{\text{kg}}{\text{kg mol}}$

Basis: 100 lb mol

Compound	lb mol	MW	lb	mass fraction
CH_4	80	16	1280	0.688
C_2H_4	10	28	280	0.151
C_2H_6	10	30	300	0.161
			1860	1.000

$$\text{Avg. MW} = \frac{1860 \text{ lb}}{100 \text{ lb mol}} = 18.6 \text{ lb/lb mol}$$

1.61 Basis: 100g mol gas

Comp	mol	MW	g
CO_2	19.3	44	849.2
N_2	72.1	28	2018.8
O_2	6.5	32	208.0
H_2O	2.1	18	37.8
	100.0		3113.8

$$\text{Avg. mol wt} = \frac{3113.8}{100.0} = 31.138$$

1.62 Basis: 200 kg of liquid

hexane free basis

	Mass frac.	MW	Moles	mol. fraction	moles	mol. fraction	fraction mass
Butane	0.4	58.12	1.376	0.467	1.376	0.5537	0.5
Pentane	0.4	72.15	1.109	0.376	1.109	0.4463	0.5
Hexane	0.2	86.17	0.464	0.157	-	-	-
	1.0		2.949		2.485		

1.63 Basis: 100 kg coal.

Elements in VCM: Carbon, Hydrogen, sulfur, nitrogen, oxygen

$$\text{Mass of carbon in VCM} = 79.9 \text{ kg} - 69.3 \text{ kg} = 10.6 \text{ kg}$$

$$\text{Mass of sulfur in VCM} = 0.69 \text{ kg}$$

$$\text{Mass of nitrogen in VCM} = 1.30 \text{ kg}$$

$$\text{Mass of moisture (H}_2\text{O)} = 3.2 \text{ kg}$$

$$\text{No. of moles of H}_2\text{O} = \frac{3.2 \text{ kg}}{18 \text{ kg/kgmol}} = 0.178 \text{ kg mol}$$

(continued)

Solutions - Chapter - 1

which corresponds to 0.178 kg mol O and 2 (0.178) kg mol H
 $\therefore$ mass of O in moisture = 0.178 (16) = 2.85 kg O
 mass of H in moisture = 2(0.178) (1.008) = 0.36 kg H
 Mass of O in VCM = 6.76 - 2.85 = 3.91 kg O
 Mass of H in VCM = 4.85 - 0.36 = 4.49 kg H

To summarize,

Component	kg	wt. percent
C	10.6	0.51
S	0.69	0.03
N	1.30	0.06
H	4.49	0.21
O	<u>3.91</u>	<u>0.19</u>
	21	1.00

1.64 Basis: 100 kg mol gas

Comp.	kg mol = %	mol wt	kg	mass fraction	%
CH ₄	20	16	320	0.085	8.5
C ₂ H ₆	5	30	150	0.040	4.0
CO ₂	<u>75</u>	<u>44</u>	<u>3300</u>	<u>0.875</u>	<u>87.5</u>
Total	100		3770	1.000	100.0

1.65 Basis: 100 kg mol gas. Let x = kg of B

Component	percent = kg mol	Mol. wt.	kg
Argon	40	40	1600
B	40	x/40	x
C	<u>40</u>	<u>50</u>	<u>1000</u>
Total	100.0		2600 + x

$$x = 0.1875 (2600 + x).$$

$$x - 0.1875x = 0.1875 (2600)$$

$$x = \frac{487.5}{0.8125} = 600$$

a) molecular wt. of B = $\frac{x}{40} = \frac{600}{40} = \boxed{15 \text{ kg / kg mol}}$

b) Average molecular wt = $\frac{2600 + x}{100.0}$

$$= \frac{3200}{100} = \boxed{32 \text{ kg / kg mol}}$$

- 1.66 The gas has oxygen plus "other gases". Assume the average molecular weight the "other gases" to be some unknown quantity: MW_{unknown} (its value is not needed in the calculations).

Basis: 1.0 mole of the gas mixture. Let x be the mole fraction of oxygen. Then $(1-x)$ is the mole fraction of the "other gases."

$$\text{average molecular weight} = \sum (\text{mol wt})_i (\text{mole fraction})_i$$

Substituting:

with correct oxygen molecular weight:

$$32x + MW_{\text{unknown}}(1-x) = 39.2 \quad (1)$$

with incorrect oxygen molecular weight:

$$16x + MW_{\text{unknown}}(1-x) = 32.8 \quad (2)$$

Solving equations (1) and (2) and subtracting,

$$(32x - 16x) = 16x = (39.2 - 32.8) = 6.4$$

$$x = \frac{6.4}{16} = 0.4 = \text{mole fraction of } O_2$$

$$\text{mole percent oxygen} = \boxed{40\%}$$

- 1.67 $T_K = -10 + 273 = 263K$
 $T_{\circ F} = -10(1.8) + 32 = 14^{\circ F}$
 $T_{\circ R} = 14 + 460 = 474^{\circ R}$

- 1.68 Yes, if the temperature scale is a relative one ($^{\circ}C$, $^{\circ}F$).
 No, if the scale is absolute.

$$1.69 \quad C_p = 8.41 + \left[\frac{2.4346 \times 10^{-5} T_K}{\left(2.4346 \times 10^{-5} \frac{J}{(\text{gmol})(K)^2} \right)} \right] (T_K)$$

$$\text{Substitute} \quad 1.8 T_K = T_{\circ R}$$

$$\begin{aligned} C_p &= 8.41 + 2.4346 \times 10^{-5} \frac{J}{(\text{gmol})(K)^2} \left(\frac{T_{\circ R}}{1.8} \right) \\ &= \boxed{8.41 + 1.353 \times 10^{-5} T_{\circ R}} \end{aligned}$$

1.70

$$a) \quad \frac{10^{\circ}\text{C}}{1.0^{\circ}\text{C}} \left| \frac{1.8^{\circ}\text{F}}{1.0^{\circ}\text{C}} \right| + 32 = \boxed{50^{\circ}\text{F}}$$

$$b) \quad \frac{10^{\circ}\text{C}}{1.0^{\circ}\text{C}} \left| \frac{1.8^{\circ}\text{F}}{1.0^{\circ}\text{C}} \right| + 32 + 460^{\circ}\text{R} = \boxed{510^{\circ}\text{R}}$$

$$c) \quad \frac{-25^{\circ}\text{F}}{1.8^{\circ}\text{F}} \left| \frac{1.0^{\circ}\text{C}}{1.8^{\circ}\text{F}} \right| - 32 + 273\text{K} = \boxed{241.3\text{K}}$$

$$d) \quad \frac{150\text{K}}{1.0\text{K}} \left| \frac{1.8^{\circ}\text{R}}{1.0\text{K}} \right| = \boxed{270^{\circ}\text{R}}$$

1.71 First multiply the RHS of the equation so that

$$\frac{\text{Btu}}{(\text{lbmol})(^{\circ}\text{F})} \left| \frac{1054.8\text{J}}{1\text{Btu}} \right| \left| \frac{1\text{lb mol}}{454\text{ gmol}} \right| \left| \frac{1.8^{\circ}\text{F}}{1.0^{\circ}\text{C}} \right| \left| \frac{1^{\circ}\text{C}}{1\text{K}} \right|$$

$$= 4.182 \frac{\text{J}}{(\text{gmol})(^{\circ}\text{K})}$$

and substitute $T^{\circ}\text{F} = 1.8T^{\circ}\text{C} + 32$

$$C_p = \left[8.448 + 0.5757 \times 10^{-2} (1.8T^{\circ}\text{C} + 32) - 0.2159 \times 10^{-5} (1.8T^{\circ}\text{C} + 32)^2 + 0.3059 \times 10^{-9} (1.8T^{\circ}\text{C} + 32)^3 \right] 4.182 \frac{\text{J}}{(\text{gmol})(^{\circ}\text{K})}$$

Simplifying,

$$C_p = 36.05 + 0.0447T - 0.2874 \times 10^{-4} T^2 + 0.7424 \times 10^{-8} T^3$$

1.72 The instrument does not contain mercury, but has to be one that responds at -76°C and can be calibrated to measure temperature.

1.73 The first sentence really means that the unit interval $\Delta^{\circ}\text{C} = \text{the unit interval } \Delta\text{K}$. However, $^{\circ}\text{C} \neq \text{K}$ as a temperature measure. The second sentence is satisfactory when referred to temperature, but the "only difference" should be omitted. Third sentence; there is no difference in the precision but the reported value of temperature may be rounded off to leave fewer significant figures (unlikely as much as one digit).

Solutions - Chapter - 1

1.74 Basis: given temperatures*

	$^{\circ}\text{F}$	$^{\circ}\text{R}$	K	$^{\circ}\text{C}$
a.	140*	600	333	60
b.	77	537	298*	25
c.	-40	500*	277.5	-4.5
d.	-40	420	233	-40*
e.	1000*	1460	810	537
f.	540	1000*	555	282
g.	1340	1800	1000*	727
h.	1832	2292	1273	1000*

1.75

Basis: $0.171 \times 10^{-8} \frac{\text{Btu}}{(\text{ft})^2(\text{hr})(^{\circ}\text{R})^4}$

$$\frac{0.17 \times 10^{-8} \text{ Btu}}{(\text{ft})^2(\text{hr})(^{\circ}\text{R})^2} \left| \frac{(1.8^{\circ}\text{R})^4}{(1 \text{ K})^4} \right| \left| \frac{\text{hr}}{3600\text{s}} \right| \left| \frac{(\text{ft})^2}{144(\text{in})^2} \right| \left| \frac{(\text{in})^2}{(2.54\text{cm})^2} \right| \left| \frac{(100 \text{ cm})^2}{(1 \text{ m})^2} \right| \left| \frac{1.055 \times 10^3 \text{ J}}{1 \text{ Btu}} \right|$$

$$\boxed{\frac{5.67 \times 10^{-8} \text{ J}}{(\text{m})^2(\text{s})(\text{K})^4}}$$

1.76 The pressure cited may be the highest barometric pressure but not the highest absolute or relative pressure.

1.77 Basis: Dept = 100 m $p = p_o + \rho gh$

1 atm +

$$\frac{1000 \text{ m}}{\text{cm}^3} \left| \frac{1.024 \text{ g}}{\text{cm}^3} \right| \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \left| \frac{(100 \text{ cm})^3}{(1 \text{ m})^3} \right| \left| \frac{1 \text{ N}}{(\text{kg})(\text{m})} \right| \left| \frac{1 \text{ kPa}}{1 \text{ N}} \right| \left| \frac{1 \text{ atm}}{1.013 \times 10^5 \text{ N/m}^2} \right|$$

$$= \frac{100.1 \text{ atm}}{1 \text{ atm}} = \boxed{1.014 \times 10^4 \text{ kPa}}$$

1.78 Basis: 300 kPa absolute

$$a. \frac{300 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{14.7 \text{ psia}}{101.3 \text{ kPa}} \right| = \boxed{43.5 \text{ psia}}$$

$$b. 300 \text{ kPa (absolute) or } 300 - 101.3 = \boxed{198.7 \text{ kPa (gauge)}}$$

$$c. \frac{300 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{101.3 \text{ kPa}} \right| = \boxed{2.96 \text{ atm}}$$

$$d. \frac{300 \text{ kPa}}{100 \text{ kPa}} \left| \frac{1 \text{ bar}}{100 \text{ kPa}} \right| = \boxed{3 \text{ bar}}$$

$$e. \frac{300 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{29.92 \text{ in Hg}}{101.3 \text{ kPa}} \right| = \boxed{88.6 \text{ in Hg}}$$

$$f. \frac{300 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{33.91 \text{ ft H}_2\text{O}}{101.3 \text{ kPa}} \right| = \boxed{100.4 \text{ ft H}_2\text{O}}$$

$$g. \frac{300 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1.0332 \text{ kg}_f/\text{cm}^2}{101.3 \text{ kPa}} \right| = \boxed{306 \frac{\text{kg}_f}{\text{cm}^2}}$$

1.79

$$a. m = \rho V = \frac{1000 \text{ kg}}{\text{m}^3} \left| \frac{10 \text{ m}}{1} \right| \left| \frac{10 \text{ m}}{1} \right| \left| \frac{0.25 \text{ m}}{1} \right| = \boxed{25,000 \text{ kg}}$$

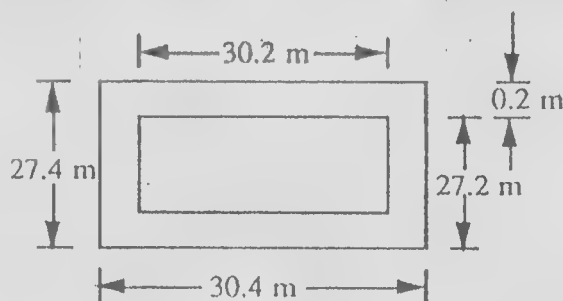
$$b. \frac{F}{A} = \frac{mg}{A} = \frac{25,000 \text{ kg}}{10 \text{ m} \times 10 \text{ m}} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \left| \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m}/\text{s}^2} \right| \left| \frac{1 \text{ Pa}}{1 \text{ N}/\text{m}^2} \right| = 2,450 \text{ Pa} = \boxed{2.45 \text{ kPa}}$$

$$c. \frac{2.450 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{101.3 \text{ kPa}} \right| \left| \frac{14.7 \text{ psi}}{1 \text{ atm}} \right| = \boxed{0.36 \text{ psi}}$$

1.80 $\rho_{\text{concrete}} = 2080 \text{ kg}/\text{m}^3$

$\rho_{\text{water}} = 1000 \text{ kg}/\text{m}^3$

Volume of concrete:



(continued)

Sides

$$V_s = \frac{5 \text{ m}}{1} \times \frac{30.2 \text{ m}}{1} \times \frac{200 \text{ mm}}{1000 \text{ mm}} \times \frac{1 \text{ m}}{1} \times \frac{2 \text{ sides}}{1} = 60.4 \text{ m}^3$$

Ends

$$V_e = \frac{5 \text{ m}}{1} \times \frac{27.2 \text{ m}}{1} \times \frac{200 \text{ mm}}{1000 \text{ mm}} \times \frac{1 \text{ m}}{1} \times \frac{2 \text{ ends}}{1} = 55 \text{ m}^3$$

Floor

$$V_f = \frac{27.4 \text{ m}}{1} \times \frac{30.4 \text{ m}}{1} \times \frac{200 \text{ mm}}{1000 \text{ mm}} \times \frac{1 \text{ m}}{1} = 166.592 \text{ m}^3$$

$$\text{Total volume} = 281.992 \text{ m}^3$$

$$\text{Mass of concrete} = \frac{281.992 \text{ m}^3}{1} \times \frac{2080 \text{ kg}}{\text{m}^3} = 586,543.36 \text{ kg}$$

Volume of displaced water required to float:

$$\frac{586,543.36 \text{ kg}}{1} \times \frac{1 \text{ m}^3 \text{ H}_2\text{O}}{1000 \text{ kg H}_2\text{O}} = 586.543 \text{ m}^3$$

$$V = LWh \rightarrow h = \frac{V}{LW}$$

$$h = \frac{586.54 \text{ m}^3}{27.4 \text{ m} \times 30.4 \text{ m}} = 0.7042 \text{ m}$$

1.81 The pressure is a gauge pressure.

Basis: 50.0 psig

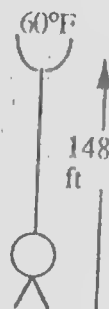
$$\text{a. } \frac{50.0 \text{ psig}}{1} \times \frac{33.91 \text{ ft H}_2\text{O}}{14.7 \text{ psia}} =$$

115 ft

(difference)

b. No. Insufficient height.

Alternate solutions can be applying $\Delta p = \rho \Delta h g$



Solutions - Chapter - 1

1.82

$$p = \rho gh \text{ so } h_{\text{Hg}} = h_{\text{kero}} \frac{\rho_{\text{kero}}}{\rho_{\text{Hg}}}; \rho_{\text{kero}} = \frac{0.82}{1.00} \frac{\text{g}}{\text{cm}^3}$$

Basis: 5 in kerosine

$$\frac{5.0 \text{ in kero}}{1 \text{ in}} \left| \frac{25.4 \text{ mm}}{1 \text{ in}} \right| \frac{0.82 \text{ g/cm}^3}{13.6 \text{ g/cm}^3} = \boxed{7.66 \text{ mm Hg}}$$

1.83 Basis: 26.2 in Hg vacuum

$$p = \frac{(30.4 - 26.2) \text{ in Hg}}{29.92 \text{ in Hg}} \left| \frac{14.7 \text{ psia}}{29.92 \text{ in Hg}} \right| = \boxed{2.06 \text{ psia}}$$

1.84

$$p = \frac{(29.31 - 3.53) \text{ in Hg}}{29.92 \text{ in Hg}} \left| \frac{760 \text{ mm Hg}}{29.92 \text{ in Hg}} \right| = \boxed{655 \text{ mm Hg}}$$

1.85 Neither John is necessarily right. The pressure at the top of Pikes Peak is continually changing.

1.86 $\Delta p = \rho gh$

$$= \frac{1 \text{ g}}{\text{cm}^3} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \left| \frac{13.1 \text{ m}}{1} \right| \frac{1 \text{ kg}}{1000 \text{ g}} \left| \frac{(100 \text{ cm})^3}{\text{m}^3} \right| \left| \frac{\text{Pa}}{1 \text{ kg/m s}^2} \right| \left| \frac{1 \text{ kPa}}{1000 \text{ Pa}} \right|$$

$$= 128.4 \text{ kPa}$$

$$\frac{F}{A} = \frac{mg}{A_{\text{Bottom}}} = \frac{\rho V g}{A_{\text{Bottom}}} = \frac{\rho (S.A.) (t) g}{A_{\text{Bottom}}}$$

$$A_{\text{Bottom}} = \frac{\pi D^2}{4} = \frac{\pi (30.5 \text{ m})^2}{4} = 730.62 \text{ m}^2$$

$$A_{\text{Top}} = 730.62 \text{ m}^2$$

$$A_{\text{side}} = \pi D h = \pi (30.5 \text{ m}) (13.1 \text{ m}) = 1255.2 \text{ m}^2$$

$$S.A. = A_{\text{Top}} + A_{\text{Bottom}} + A_{\text{Side}}$$

(continued)

$$= (730.62 + 730.62 + 1255.22) \text{ m}^2 = 2716.46 \text{ m}^2$$

$$\frac{\rho(S.A.)(1)g}{A} =$$

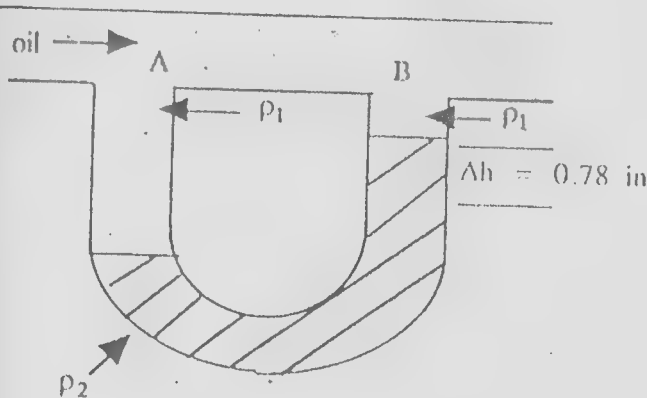
$$\frac{7.86 \text{ g}}{\text{cm}^3} \left| \frac{100 \text{ cm}^3}{\text{m}^3} \right| \frac{2716.46 \text{ m}^2}{9.35 \times 10^{-3} \text{ m}} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right|$$

$$\frac{1 \text{ kg}}{1000 \text{ g}} \left| \frac{1 \text{ Pa}}{1 \text{ kg/ms}^2} \right| \frac{1 \text{ kPa}}{1000 \text{ Pa}} = \boxed{2.68 \text{ kPa}}$$

1.87 $\Delta p = \rho gh$

$$= \frac{0.800 \text{ g}}{\text{cm}^3} \left| \frac{980 \text{ cm}}{\text{s}^2} \right| \frac{12.7 \text{ cm}}{1000 \text{ g}} \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| \frac{100 \text{ cm}}{\text{m}} \left| \frac{1 \text{ Pa}}{1 \text{ kg/ms}^2} \right| \frac{1 \text{ kPa}}{1000 \text{ Pa}} = \boxed{0.996 \text{ kPa gage}}$$

1.88



$$P_A + \rho_1 gh_1 + \rho_2 g \Delta h = P_D$$

$$P_B + \rho_1 gh_1 + \rho_2 g \Delta h = P_D$$

$$P_A - P_B = \rho_1 gh_1 + \rho_2 g \Delta h - \rho_1 gh_1 - \rho_1 g \Delta h$$

$$= \rho_2 g \Delta h_1 - \rho_1 g \Delta h = g \Delta h (\rho_1 - \rho_2)$$

$$= \frac{9.8 \text{ m}}{\text{s}^2} \left| \frac{0.78 \text{ in}}{3.28 \text{ ft}} \right| \frac{1 \text{ m}}{\text{cm}^2} \left| \frac{13.546 - 0.91 \text{ g}}{1000 \text{ g}} \right|$$

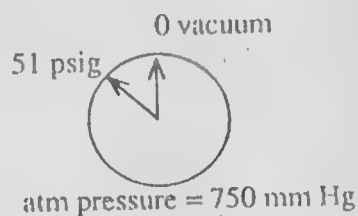
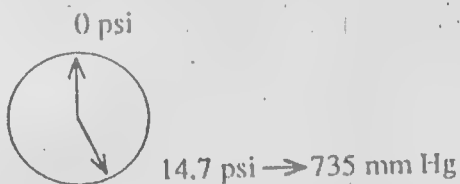
(continued)

$$\frac{1 \text{ ft}}{12 \text{ in}} \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \left| \frac{1 \text{ N}}{\text{m}^2} \right| \left| \frac{1 \text{ Pa}}{1 \text{ N}} \right| \left| \frac{760 \text{ mm Hg}}{101.3 \times 10^3 \text{ Pa}} \right|$$

$$= 18.4 \text{ mm Hg}$$

The pressure at A is higher than the pressure at B.

1.89 Vacuum Basis: 51 psig



- 1) Assume the correction to the gauge reading is directly proportional to the gauge reading. The correction is 735/760 times the gauge reading, and $51(735/760) = 49.3 \text{ psia}$
- 2) An alternate correction is to assume the needed correction is additive. Then the correction is a fixed (760-735)mmHg reduction, or 25 mm Hg. The second reading should be $51 - 25 \left(\frac{14.7}{760} \right) = 50.5 \text{ psig}$

1.90 Because the open end of the tube is inverted into the mercury end of the dish, and no air is allowed into the upper end of the tube, only the weight of the Hg column will press against the pool of Hg. This weight will balance against the atmospheric pressure pressing on the pool of mercury.

1.91

$$M = \rho_A \frac{g_c}{g} \text{ is } \frac{\text{lb}_f \text{ in}^2}{\text{in}^2} \left| \frac{\text{lb}_m(\text{ft})}{(\text{lb}_f)(\text{s}^2)} \right| \left| \frac{\text{ft}}{\text{s}^2} \right|$$

which yields lb_m so the procedure is ok, although the unit conversion becomes lost.

1.92 Basis: 20 in Hg gauge pressure

$$\frac{20 \text{ in. Hg}}{29.92 \text{ in. Hg}} \left| \frac{14.7 \text{ psi}}{1} \right| = 9.74 \text{ psi}$$

$$\frac{740 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{14.7 \text{ psi}}{1} \right| = 14.3 \text{ psia}$$

$$14.3 - 9.74 = \boxed{4.56 \text{ psia}}$$

1.93 Pressure at M = p_m $p = \rho gh$

$$\text{Pressure at 1} = p_m + (30) (\rho_{H_2O})g$$

$$\text{Pressure at 2} = p_m + (30) (\rho_{H_2O})g + h (\rho_{H_2O})g$$

$$\begin{aligned} \text{Pressure at 3} &= \text{Press. at 4} \\ &= p_m + (30) (\rho_{H_2O})g + h (\rho_{H_2O})g + 6 (\rho_{Hg})g \end{aligned}$$

$$\text{Pressure at 5} = p_m + (30) (\rho_{H_2O})g + h (\rho_{H_2O})g + 6 (\rho_{Hg})g - 6 (\rho_{H_2O})g$$

$$\begin{aligned} \text{Pressure at N} &= p_m + (30) (\rho_{H_2O})g + h (\rho_{H_2O})g + 6 (\rho_{Hg})g - 6 (\rho_{H_2O})g \\ &\quad - h (\rho_{H_2O})g = p_N \end{aligned}$$

$$\text{a) } p_N - p_M = [(30 + h - 6 - h) (\rho_{H_2O}) + 6 (\rho_{Hg})]g = \boxed{10.3 \text{ kPa}}$$

or

$$24(1) + 6(13.6) = \boxed{105.6 \text{ in. H}_2\text{O}}$$

$$\text{b) } \boxed{p_N > p_M}$$

$$1.94 \text{ Press at 1} = p_B - 6\rho_o + 3\rho_o = p_B - 3\rho_o$$

$$\text{Press at 2} = p_B - 3\rho_o + \frac{h\rho_o}{(2)(12)} = \text{Press at 3}$$

$$\text{Press at 4} = p_B - 3\rho_o + \frac{h}{24}\rho_o - \frac{h\rho_{Hg}}{(12)} = p_A$$

(continued)

$$p_B - p_A = \frac{h\rho_{Hg}}{(12)} + 3\rho_o - \frac{h}{24}\rho_o = \frac{h\rho_{Hg}}{(12)} + \rho_o\left(3 - \frac{h}{24}\right)$$

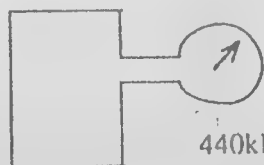
$$p_B - 14.7 = \frac{(h)(13.6)(62.4)}{(1728)} + \frac{(0.88)(62.4)(12)}{(1728)}\left(3 - \frac{h}{24}\right)$$

$$p_B = 0.491h + 1.14 - 0.0159h + 14.7$$

$$= 15.84 + 0.4751h \text{ psia}$$

1.95 Basis: 750 mm Hg

Atmospheric pressure + gauge pressure = absolute pressure



440 kPa

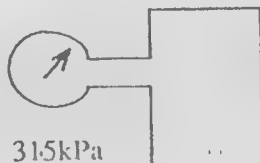
$$\frac{750 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{101.3 \text{ kPa}}{101.3 \text{ kPa}} \right. = 100 \text{ kPa}$$

$$\text{absolute pressure} = \frac{440 \text{ kPa}}{540 \text{ kPa}}$$

$$\frac{765 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{101.3 \text{ kPa}}{101.3 \text{ kPa}} \right. = 102 \text{ kPa}$$

$$540 - 102 = \boxed{438 \text{ kPa}}$$

1.96



31.5 kPa

Basis: 31.5 kPa

atmospheric pressure + gauge pressure = absolute pressure

$$98.2 - 31.5 = \boxed{66.7 \text{ kPa absolute}}$$

1.97 Basis: Data in the diagram

State 1 is before corking; state 2 is after equilibrium is reached after filling.

Assume $p_A = p_{Z1} = 29.92 \text{ in. Hg abs.}$ $p_{Z2} = p_A + \rho_{Hg}gh = 29.92 + h$ where p_{Z2} is in inches Hg.

(continued)

Solutions - Chapter - 1

Use the ideal gas law: $p_{z2} V_{z2} = p_{z1} V_{z1}$

$$p_{z2} = 29.92 (8/6) = 39.90 \text{ in. Hg}$$

$$39.92 = 29.92 + h \quad \text{or} \quad h = 9.98 \text{ in. Hg}$$

$$9.98 + 14 = \boxed{24 \text{ in. Hg}}$$

1.98 Basis: 6.6 psig

Use $\Delta p = \rho gh$ twice, once for the CCl_4 and oil, and once for the oil and water as systems; $\rho_{\text{CCl}_4} = 1.595 \text{ g/cm}^3$.

$$p_A + \rho_{\text{vap}} gh_{\text{vap}} + \rho_{\text{CCl}_4} gh_{\text{CCl}_4} = p_C + \rho_{\text{oil}} g(\Delta h) + \rho_{\text{CCl}_4} g(29.5)$$

$$p_C + \rho_{\text{oil}} g(\Delta h + 7.5) + \rho_{\text{H}_2\text{O}} g(22) = p_B + \rho_{\text{H}_2\text{O}} gh_{\text{H}_2\text{O}}$$

To simplify the two equations, neglect $\rho_{\text{vap}} gh_{\text{vap}}$. Put all of the terms in the units of inches of water. Note $\rho_1 gh_1 = \rho_2 gh_2$ for two different fluids exerting the same pressure.

$$p_A = \frac{6.6 \text{ psia}}{14.7 \text{ psia}} \left| \frac{33.91 \text{ ft H}_2\text{O}}{1 \text{ ft}} \right| \frac{12 \text{ in.}}{1 \text{ ft}} = 182.7 \text{ in. H}_2\text{O gauge}$$

$$p_B = \frac{14.7 \text{ psia}}{14.7 \text{ psia}} \left| \frac{33.91 \text{ ft H}_2\text{O}}{1 \text{ ft}} \right| \frac{12 \text{ in.}}{1 \text{ ft}} = 406.9 \text{ in. H}_2\text{O absolute}$$

$$p = 589.6 \text{ in. H}_2\text{O absolute}$$

$$\rho_{\text{CCl}_4} gh_{\text{CCl}_4} = \frac{29.5 \text{ in. CCl}_4}{1.00 \frac{\text{g H}_2\text{O}}{\text{cm}^3}} \left| \frac{1.595 \frac{\text{g CCl}_4}{\text{cm}^3}}{1.00 \frac{\text{g H}_2\text{O}}{\text{cm}^3}} \right| = 47.1 \text{ in. H}_2\text{O}$$

$$\rho_{\text{oil}} gh_{\text{oil}} = \frac{7.5 \text{ in. oil}}{1.00 \frac{\text{g H}_2\text{O}}{\text{cm}^3}} \left| \frac{0.7 \frac{\text{g oil}}{\text{cm}^3}}{1.00 \frac{\text{g H}_2\text{O}}{\text{cm}^3}} \right| = 5.3 \text{ in. H}_2\text{O}$$

(continued)

Solve this second equation for p_C and substitute for p_C in the first equation.
Note that $\rho_{oil}g\Delta h$ cancels.

$$589.6 + 47.1[406.9 + h_{H_2O} - 5.3 - 22] + 47.1$$

$$h_{H_2O} = 155.4 \text{ in. } H_2O$$

1.99 $\rho_{Hg}gh_{Hg} = \rho_{fluid}gh_{fluid}$

$$267 - 211 = 56 \text{ mm Hg} = 5.6 \text{ cm Hg}$$

$$\rho_{fluid} = \frac{\rho_{Hg}gh_{Hg}}{gh_{fluid}} = \frac{13.546 \text{ g/cm}^3}{72.8 \text{ cm fluid}} \cdot 5.6 \text{ cm Hg}$$

$$= 1.04 \text{ g/cm}^3$$

1.100 The pressure measured by the DP cell is $\Delta p = \rho_{liquid}gz_{liquid} + \rho_{vapor}gz_{vapor}$.
The pressure is too high by $(\rho_{vapor}gz_{vapor})$ and Δp is too high by

$$\left[\left(\frac{\rho_{vapor}z_{vapor}}{\rho_{liquid}z_{liquid}} \right) + 1 \right]$$

1.101 Surface Area

$$\text{Top: } \frac{\pi D^2}{4} = \pi \frac{(8)^2 \text{ m}^2}{4} = 50.3 \text{ m}^2$$

$$\text{Walls: } \pi Dh = \pi(8\text{m})(10\text{m}) = 251.3 \text{ m}^2$$

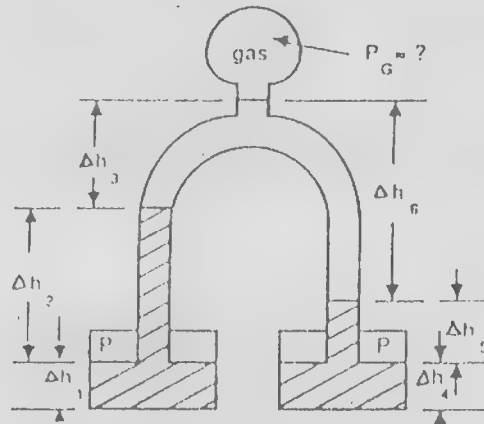
$$\text{Total area} = 301.6 \text{ m}^2$$

$$\text{Vented area needed} = \frac{0.41(\text{kPa})^{0.5}(301.6 \text{ m}^2)}{(7.5 \text{ kPa})^{1/2}}$$

$$= 45.1 \text{ m}^2$$

— Therefore, the area is **not sufficient.**

1.102



$$P_G = 12.50 - \frac{62.4 \text{ lb}_m}{\text{ft}^3} \left| \frac{g \text{ ft/s}^2}{g_c (\text{lb}_m)(\text{ft})} \right| \frac{(420 - 380) \text{ mm}}{(\text{lb}_f)(\text{s}^2)} \left| \frac{1 \text{ in}}{25.4 \text{ mm}} \right| \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| \left| \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right|$$

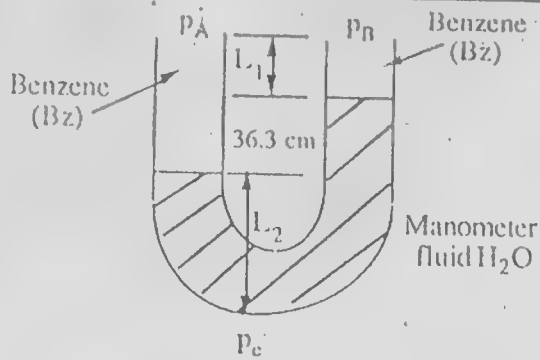
$$- \frac{(13.6) 62.4 \text{ lb}_m}{\text{ft}^3} \left| \frac{g \text{ ft/s}^2}{g_c (\text{lb}_m)(\text{ft})} \right| \frac{200 \text{ mm}}{(\text{lb}_f)(\text{s}^2)} \left| \frac{1 \text{ in}}{25.4 \text{ mm}} \right| \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| \left| \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right|$$

$$= 12.50 - 0.0569 - 3.87 = \boxed{8.57 \text{ psia}}$$

Pressure conversions can be made as follows instead of as above.

$$\frac{(420 - 380) \text{ mm H}_2\text{O}}{25.4 \text{ mm}} \left| \frac{1 \text{ in}}{12 \text{ in}} \right| \left| \frac{14.7 \text{ psia}}{33.91 \text{ ft H}_2\text{O}} \right| = \boxed{0.0569 \text{ psia}}$$

1.103



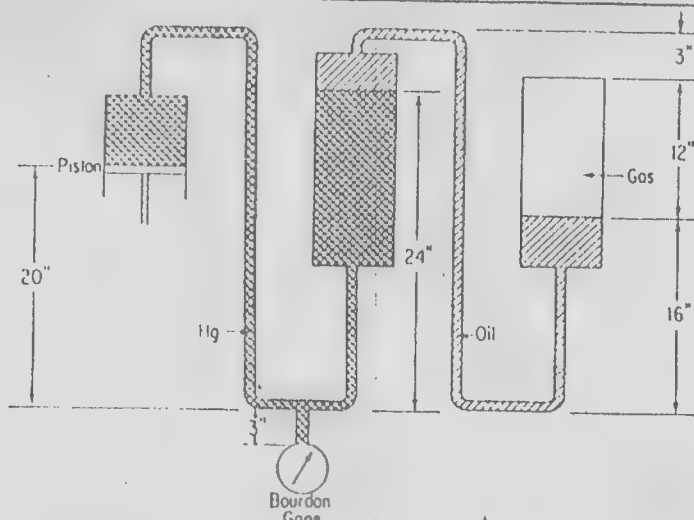
$$\begin{aligned}
 p_c &= p_A + \rho_{BZ} g L_1 + \rho_{BZ} g (36.3) \\
 &\quad + \rho_{H_2O} g L_2 \\
 &= p_B + \rho_{BZ} g L_1 + \rho_{H_2O} g (36.3) \\
 &\quad + \rho_{H_2O} g L_2
 \end{aligned}$$

$$p_A - p_B = (\rho_{H_2O} - \rho_{BZ}) g (36.6) =$$

$$\frac{(0.997 - 0.879) \text{ g}}{\text{cm}^3} \left| \frac{980 \text{ cm}}{\text{s}^2} \right| \frac{36.3 \text{ cm}}{100 \text{ cm}} \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| \frac{1 \text{ N}}{(\text{kg})(\text{m})/\text{s}^2} \left| \frac{1 \text{ kPa}}{10^3 \text{ N/m}^2} \right| =$$

$$0.42 \text{ kPa}$$

1.104



$$\text{Pressure at A} = 33.1 \text{ psig} + \frac{720 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{14.7 \text{ psia}}{14.7 \text{ psia}} \right| = 47.0 \text{ psia}$$

$$p_A = \frac{47.0 \text{ psia}}{14.7 \text{ psia}} \left| \frac{101.3 \text{ kPa}}{101.3 \text{ kPa}} \right| = 324 \text{ kPa}$$

$$p_A = p_C + \rho_{oil} g (7 \text{ in}) + \rho_{Hg} g (24 \text{ in})$$

$$p_E = p_C + \rho_{oil} g (31 \text{ in}) = p_G + \rho_{oil} g (16 \text{ in})$$

(continued)

$$p_G = p_C + \rho_{oil}g(15 \text{ in}) = 324 \text{ kPa} - \rho_{oil}g(7 \text{ in}) - \rho_{Hg}g(24 \text{ in})$$

$$+ \rho_{oil}g(15 \text{ in}) = 324 \text{ kPa}$$

$$+ \frac{0.80 \text{ g}}{\text{cm}^3} \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{8 \text{ in}}{1 \text{ in}} \right| \left| \frac{0.0254 \text{ m}}{1 \text{ in}} \right| \left| \frac{1 \text{ N}}{(\text{kg})(\text{m})/\text{s}^2} \right| \left| \frac{1 \text{ kPa}}{10^3 \text{ N}/\text{m}^2} \right|$$

$$- \frac{13.6 \text{ g}}{\text{cm}^3} \left| \frac{1 \text{ kg}}{10^3 \text{ g}} \right| \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{24 \text{ in}}{1 \text{ in}} \right| \left| \frac{0.0254 \text{ m}}{1 \text{ in}} \right| \left| \frac{1 \text{ N}}{(\text{kg})(\text{m})/\text{s}^2} \right| \left| \frac{1 \text{ kPa}}{10^3 \text{ N}/\text{m}^2} \right| = \boxed{244 \text{ kPa}}$$

Alternate solution: $p_G = p_A - p_{AB} + p_{BD}$

$$p_G = 324 \text{ kPa} - \frac{24 \text{ in Hg}}{29.92 \text{ in Hg}} \left| \frac{101.3 \text{ kPa}}{1 \text{ atm}} \right|$$

$$+ \frac{8 \text{ in oil}}{1 \text{ in oil}} \left| \frac{0.80 \text{ in H}_2\text{O}}{1 \text{ ft}} \right| \left| \frac{1 \text{ ft}}{12 \text{ in}} \right| \left| \frac{101.3 \text{ kPa}}{33.91 \text{ ft H}_2\text{O}} \right| = \boxed{244 \text{ kPa}}$$

1.105



Mol. wt.: 208.3 142.05 233.4 58.45

a. Basis: 5.0 g Na_2SO_4

$$\text{Example: } \frac{5 \text{ g Na}_2\text{SO}_4}{142.05 \text{ g Na}_2\text{SO}_4} \left| \frac{1 \text{ g mol Na}_2\text{SO}_4}{1 \text{ g mol Na}_2\text{SO}_4} \right| \left| \frac{1 \text{ g mol BaCl}_2}{1 \text{ g mol BaCl}_2} \right| \left| \frac{208.3 \text{ g BaCl}_2}{1 \text{ g mol BaCl}_2} \right| =$$

$$\boxed{7.33 \text{ g BaCl}_2}$$

Problem	Basis	Answer
b.	5 g BaSO_4	4.47 g BaCl_2
c.	5 g NaCl	8.91 g BaCl_2
d.	5 g BaCl_2	3.41 g Na_2SO_4
e.	5 g BaSO_4	3.04 g Na_2SO_4
f.	5 lb NaCl	6.08 lb Na_2SO_4
g.	5 lb BaCl_2	5.59 lb BaSO_4
h.	5 lb Na_2SO_4	8.21 lb BaSO_4
i.	5 lb NaCl	9.98 lb BaSO_4

Solutions - Chapter - 1

1.106



Mol. wt.: 169.89 58.45 143.3 85.01

a. Basis: 5.0 g NaCl

$$\text{Example: } 5.0 \text{ NaCl} \left| \frac{1 \text{ g mol NaCl}}{58.45 \text{ g NaCl}} \right| \left| \frac{1 \text{ g mol AgNO}_3}{1 \text{ g mol NaCl}} \right| \left| \frac{169.89 \text{ g AgNO}_3}{1 \text{ g mol AgNO}_3} \right| =$$

14.53 g AgNO₃

Problem	Basis	Answer
b.	5 g AgCl	5.92 g AgNO ₃
c.	5 g NaNO ₃	10.00 g AgNO ₃
d.	5 g AgNO ₃	1.721 g NaCl
e.	5 g AgCl	2.04 g NaCl
f.	5 lb NaNO ₃	3.44 lb NaCl
g.	5 lb AgNO ₃	4.22 lb AgCl
h.	5 lb NaCl	12.27 lb AgCl
i.	5 lb AgNO ₃	4.22 lb AgCl

1.107 Basis: 1 ton dolomite



Assume complete reactions



Comp.	%	lb	mol.wt.	lb mol that react
CaCO ₃	68	1360	100.0	13.60
MgCO ₃	30	600	84.3	7.13
SiO ₂	2	40	60.0	
Total	100	2000		20.73

$$\text{a. } \frac{20.73 \text{ lb mol react}}{\text{ton dolomite}} \left| \frac{1 \text{ mol CO}_2 \text{ produced}}{1 \text{ mol react}} \right| \left| \frac{44 \text{ lb}}{1 \text{ lb mol CO}_2} \right| = \boxed{912 \text{ lb CO}_2}$$

$$\text{b. } \frac{20.73 \text{ lb mol react}}{\text{ton dolomite}} \left| \frac{1 \text{ mol H}_2\text{SO}_4 \text{ reqd}}{1 \text{ mol react}} \right| \left| \frac{98 \text{ lb H}_2\text{SO}_4}{1 \text{ mole H}_2\text{SO}_4} \right| \left| \frac{100 \text{ lb acid}}{94 \text{ lb H}_2\text{SO}_4} \right| = \boxed{2160 \text{ lb acid}}$$

Solutions – Chapter - 1

1.108 Basis: 2 g mol

$$C: 6 \times 12 = 72 \quad H: 8 \times 1 = 8 \quad O: 6 \times 16 = 96$$

$$\text{mol. wt.} = 72 + 8 + 96 = 176$$

$$\frac{2 \text{ g mol}}{1 \text{ g mol}} \left| \frac{176 \text{ g}}{454 \text{ g}} \right| \frac{1 \text{ lb}}{1} = \boxed{0.775 \text{ lb}}$$

1.109



$$\text{mol. wt.} \quad (23.7) \quad (44.01) \quad (73.88) \quad (18.00)$$

a. Basis: 1.00 kg CO₂

$$\frac{1 \text{ kg CO}_2}{44.01 \text{ kg CO}_2} \left| \frac{1 \text{ kg mol CO}_2}{1 \text{ kg mol CO}_2} \right| \frac{2 \text{ kg mol LiOH}}{1 \text{ kg mol CO}_2} \left| \frac{23.9 \text{ kg LiOH}}{1 \text{ kg mol LiOH}} \right| = \boxed{1.09 \text{ kg LiOH}}$$

b. Basis: 100 kg LiOH $2\text{NaOH} + \text{CO}_2 \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$

$$\frac{100 \text{ kg LiOH}}{23.94 \text{ kg LiOH}} \left| \frac{1 \text{ kg mol LiOH}}{1 \text{ kg mol LiOH}} \right| \frac{1 \text{ kg mol NaOH}}{1 \text{ kg mol LiOH}} \left| \frac{40.0 \text{ kg NaOH}}{1 \text{ kg mol NaOH}} \right| = \boxed{167.1 \text{ kg NaOH}}$$

$$\text{Penalty} = \frac{(167.1 - 100)}{100} (100) = \boxed{67.1\%}$$

1 2 1
1 2 1

1.110 Basis: 2000 tons 93.2% H₂SO₄ (1 day)

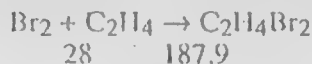
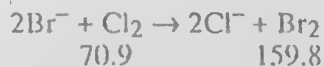
$$\text{a. } \frac{2000 \text{ tons soln}}{1 \text{ ton soln}} \left| \frac{0.932 \text{ ton H}_2\text{SO}_4}{98 \text{ ton H}_2\text{SO}_4} \right| \frac{1 \text{ ton mole H}_2\text{SO}_4}{1 \text{ mol H}_2\text{SO}_4} \left| \frac{1 \text{ mol S}}{1 \text{ mol H}_2\text{SO}_4} \right| \frac{32 \text{ ton S}}{1 \text{ ton mol S}} = \boxed{609 \text{ ton S}}$$

$$\text{b. } \frac{609 \text{ ton S}}{32 \text{ ton S}} \left| \frac{1 \text{ ton mol S}}{1 \text{ mol S}} \right| \frac{1.5 \text{ mol O}_2}{1 \text{ ton mol O}_2} \left| \frac{32 \text{ ton O}_2}{1 \text{ ton mol O}_2} \right| = \boxed{913.5 \text{ ton O}_2}$$

$$\text{c. } \frac{609 \text{ ton S}}{32 \text{ ton S}} \left| \frac{1 \text{ ton mole S}}{1 \text{ mol S}} \right| \frac{1 \text{ mole H}_2\text{O}}{1 \text{ ton mol H}_2\text{O}} \left| \frac{18 \text{ ton H}_2\text{O}}{1 \text{ ton mol H}_2\text{O}} \right| = \boxed{342.6 \text{ ton H}_2\text{O}}$$

Solutions - Chapter - 1

1.111 Basis: 1 lb Br₂



$$\text{a. } \frac{0.27 \text{ lb acid}}{2000 \text{ lb seawater}} \left| \frac{1 \times 10^6 \text{ lb seawater}}{65 \text{ lb Br}_2} \right| = \boxed{2.08 \text{ lb } 98\% \text{ H}_2\text{SO}_4 / \text{lb Br}_2}$$

$$\text{b. } \frac{1 \text{ lb Br}_2}{159.9 \text{ lb Br}_2} \left| \frac{\text{mole Br}_2}{1 \text{ mole Br}_2} \right| \left| \frac{1 \text{ mole Cl}_2}{1 \text{ mole Br}_2} \right| \left| \frac{70.9 \text{ lb Cl}_2}{\text{mole Cl}_2} \right| = \boxed{0.445 \text{ lb Cl}_2}$$

$$\text{c. } \frac{1 \text{ lb Br}_2}{65 \text{ lb Br}_2} \left| \frac{1 \times 10^6 \text{ lb sea water}}{65 \text{ lb Br}_2} \right| = \boxed{15,400 \text{ lb seawater}}$$

$$\text{d. } \frac{1 \text{ lb Br}_2}{159.9 \text{ lb Br}_2} \left| \frac{\text{mole Br}_2}{1 \text{ mole Br}_2} \right| \left| \frac{1 \text{ mole C}_2\text{H}_4\text{Br}_2}{1 \text{ mole Br}_2} \right| \left| \frac{187.9 \text{ lb C}_2\text{H}_4\text{Br}_2}{1 \text{ mole C}_2\text{H}_4\text{Br}_2} \right| = \boxed{1.176 \text{ lb C}_2\text{H}_4\text{Br}_2}$$

1.112

a)

	<u>LHS</u>	<u>RHS</u>
C	4	4
H	10	10
Zn	1	1
O	14	14

Yes, the equation is balanced.

b) Basis: 1.5 kg H₂O

$$\frac{1.5 \text{ kg ZnO}}{1.0 \text{ kg ZnO}} \left| \frac{1000 \text{ g ZnO}}{81.40 \text{ g ZnO}} \right| \left| \frac{1 \text{ gmol ZnO}}{1 \text{ gmol ZnO}} \right| \left| \frac{1 \text{ gmol DEZ}}{1 \text{ gmol DEZ}} \right| \left| \frac{123.4 \text{ g DEZ}}{1 \text{ gmol DEZ}} \right|$$

$$\times \frac{1.0 \text{ kg DEZ}}{1000 \text{ g DEZ}} = \boxed{2.27 \text{ kg DEZ}}$$

$$\text{c) } \frac{20 \text{ cm}^3 \text{ H}_2\text{O}}{1 \text{ cm}^3 \text{ H}_2\text{O}} \left| \frac{1.0 \text{ g H}_2\text{O}}{18.0 \text{ g H}_2\text{O}} \right| \left| \frac{1.0 \text{ gmol H}_2\text{O}}{5 \text{ gmol H}_2\text{O}} \right| \left| \frac{1 \text{ gmol DEZ}}{1 \text{ gmol DEZ}} \right| \left| \frac{123.4 \text{ g DEZ}}{1 \text{ gmol DEZ}} \right|$$

$$= \boxed{27.4 \text{ g DEZ}}$$

1.113

$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	$\frac{\text{MW}}{277.9}$	$\text{FeSO}_4 \cdot \text{H}_2\text{O}$	$\frac{\text{MW}}{169.9}$
$\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$	223.9	FeSO_4	151.9

It is best to evaluate the three types of ferrous sulfate in terms of the cost/ton of FeSO_4 .

a. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$: Basis: 475 ton material

$$\frac{\$83,766.25}{475 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} = \boxed{\$176.35 / \text{ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} \text{ which is equivalent to}$$

$$\frac{\$176.35}{1 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} \left| \frac{277.9 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}}{1 \text{ ton mol } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} \right| \left| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}}{1 \text{ ton mol } \text{FeSO}_4} \right|$$

$$\frac{1 \text{ ton mol } \text{FeSO}_4}{151.9 \text{ ton } \text{FeSO}_4} = \$323/\text{ton } \text{FeSO}_4$$

b. $\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$:

$$\frac{\$323}{1 \text{ ton } \text{FeSO}_4} \left| \frac{151.9 \text{ ton } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4} \right| \left| \frac{1 \text{ ton mol } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}} \right| \left| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}}{223.9 \text{ ton } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}} \right|$$

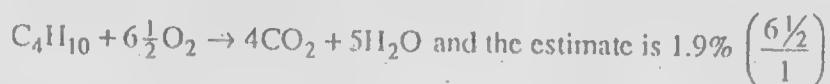
$$= \boxed{\$219 / \text{ton } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}}$$

c. $\text{FeSO}_4 \cdot \text{H}_2\text{O}$:

$$\frac{\$323}{1 \text{ ton } \text{FeSO}_4} \left| \frac{151.9 \text{ ton } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4} \right| \left| \frac{1 \text{ ton mol } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4 \cdot \text{H}_2\text{O}} \right| \left| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot \text{H}_2\text{O}}{169.9 \text{ ton } \text{FeSO}_4 \cdot \text{H}_2\text{O}} \right|$$

$$= \boxed{\$289 / \text{ton } \text{FeSO}_4 \cdot \text{H}_2\text{O}}$$

1.114 The reaction is



$\boxed{12.4\%}$

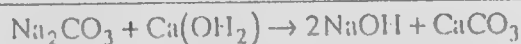
1.115 Basis: 1 L solution = 1000 g H₂O

$$\frac{50 \text{ g H}_2\text{S}}{10^6 \text{ g soln}} \left| \frac{1 \text{ g mol H}_2\text{S}}{34 \text{ g H}_2\text{S}} \right| \left| \frac{1 \text{ g mol HOCl}}{1 \text{ g mol H}_2\text{S}} \right| \left| \frac{52.45 \text{ g HOCl}}{1 \text{ g mol HOCl}} \right| \left| \frac{100 \text{ g HOCl soln}}{5 \text{ g HOCl}} \right|$$

$$\frac{1000 \text{ g soln}}{1 \text{ L soln}} \left| \frac{2}{1} \right| = \boxed{3.08 \text{ g HOCl solution}}$$

You can use the density of H₂O for the density of the solution as the H₂S content has negligible effect on the density.

1.116



Basis: 1 ton of soda ash (Na₂CO₃)

$$\frac{1 \text{ ton Na}_2\text{CO}_3}{106 \text{ ton Na}_2\text{CO}_3} \left| \frac{1 \text{ ton mol Na}_2\text{CO}_3}{1 \text{ ton mol Na}_2\text{CO}_3} \right| \left| \frac{2 \text{ ton mol NaOH}}{1 \text{ ton mol Na}_2\text{CO}_3} \right| \left| \frac{40.0 \text{ ton NaOH}}{1 \text{ ton mol NaOH}} \right| =$$

0.755 ton NaOH

$$\frac{\$130}{1 \text{ ton Na}_2\text{CO}_3} \left| \frac{1 \text{ ton Na}_2\text{CO}_3}{0.755 \text{ NaOH}} \right| = \boxed{\$172 / \text{ton Na}_2\text{CO}_3}$$

The above result is for the case of free Ca(OH₂). Otherwise, the value must be reduced to compensate for the cost of the Ca(OH₂) -- which might come from the CaCO₃ produced, and possibly be cheaper than Ca(OH₂) purchased directly.

1.117

Basis: 100 kg mol CaCO₃ fed to kiln

70% reacts

$$\text{Product: } \frac{70 \text{ kg mol CaO}}{1 \text{ kg mol CaO}} \left| \frac{57 \text{ kg CaO}}{1 \text{ kg mol CaO}} \right| = 3990 \text{ kg CaO}$$

$$\frac{70 \text{ kg mol CO}_2}{1 \text{ kg mol CO}_2} \left| \frac{44 \text{ kg CO}_2}{1 \text{ kg mol CO}_2} \right| = 3080 \text{ kg CO}_2$$

(continued)

Solutions – Chapter - 1

$$\frac{30 \text{ kg mol CaCO}_3}{1 \text{ kg mol CaCO}_2} \left| \frac{101 \text{ kg CaCO}_3}{1 \text{ kg mol CaCO}_2} \right| = 3030 \text{ kg CaCO}_3$$

170 kg mol total

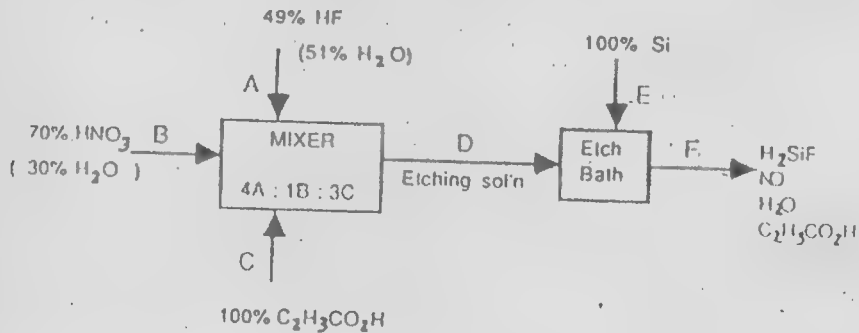
But, solid phase neglects CO₂, so Mass = 3990 + 3030 = 7020 lb
Moles = 70 + 30 = 100 lb mol

a. $\text{CaO} = \frac{3990}{7020} = \boxed{56.8\%}$

$\text{CaCO}_3 = \frac{3030}{7020} = \boxed{43.2\%}$

b. $\frac{3080 \text{ CO}_2 \text{ produced}}{100 \text{ kg mol CaCO}_3} \left| \frac{1 \text{ kg mol CaCO}_3}{100.09 \text{ kg limestone}} \right| = \boxed{0.305 \text{ kg CO}_2 \text{ produced}}$

1.118



a: Si to be removed:

$$\frac{20 \times 10^{-4} \text{ cm}}{\text{side}} \left| \frac{2 \text{ side}}{\text{wafer}} \right| \left| \frac{6000 \text{ wafer}}{\text{hr}} \right| \left| \frac{\pi (15.0 \text{ cm})^2}{4} \right| \left| \frac{2.33 \text{ g Si}}{\text{cm}^3} \right| \left| \frac{\text{mol Si}}{28.09 \text{ g Si}} \right| = 351.79 \frac{\text{mol Si}}{\text{hr}}$$

Basis: 1 L B

Limiting reactant: HNO₃ (see below). Etching solution flow rate is 279.312 kg/hr (see below).
Acetic acid not involved in the reaction.

(continued)

Moles HNO_3 :

$$\frac{8,000 \text{ cm}^3 \text{ Etch Soln}}{8 \text{ cm}^3 \text{ Etch soln}} \left| \frac{1 \text{ cm}^3 \text{ HNO}_3 \text{ Soln}}{\text{cm}^3 \text{ HNO}_3 \text{ Soln}} \right| \frac{1.4134 \text{ g HNO}_3 \text{ Soln}}{100 \text{ g HNO}_3 \text{ Soln}} \left| \frac{70 \text{ g HNO}_3}{100 \text{ g HNO}_3 \text{ Soln}} \right|$$

$$\frac{\text{mol HNO}_3}{63 \text{ g HNO}_3} = 15.70 \text{ mol HNO}_3$$

$$\frac{8,000 \text{ cm}^3 \text{ D}}{8 \text{ cm}^3 \text{ D}} \left| \frac{4 \text{ cm}^3 \text{ A}}{\text{cm}^3 \text{ A}} \right| \frac{1.198 \text{ g A}}{100 \text{ g A}} \left| \frac{49 \text{ g HF}}{20 \text{ g HF}} \right| \frac{\text{mol HF}}{20 \text{ g HF}} = 117.40 \text{ mol HF}$$

b. Limiting reactant from reaction equations:

If all HF reacts

$$\frac{117.4 \text{ mol HF}}{18 \text{ mol HF}} \left| \frac{3 \text{ mol Si}}{18 \text{ mol HF}} \right| = 19.57 \text{ mol Si consumed}$$

If all HNO_3 reacts

$$\frac{15.7 \text{ mol HNO}_3}{4 \text{ mol HNO}_3} \left| \frac{3 \text{ mol Si}}{4 \text{ mol HNO}_3} \right| = 11.78 \text{ mol Si consumed}$$

Thus, the amount of Si consumed is limited by the amount of HNO_3 .Limiting Reactant: $\boxed{\text{HNO}_3}$

c. Etching solution:

$$\frac{1 \text{ L B}}{11.78 \text{ mol Si}} \left| \frac{351.79 \text{ mol Si}}{\text{hr}} \right| = 29.86 \frac{\text{L B}}{\text{hr}} \quad \frac{29.86 \text{ L B}}{\text{hr}} \left| \frac{1.4134 \text{ kg B}}{\text{L B}} \right| = 42.209 \frac{\text{kg B}}{\text{hr}}$$

$$\frac{4 \text{ L A}}{1 \text{ L B}} \left| \frac{29.86 \text{ L B}}{\text{hr}} \right| \left| \frac{1.1980 \text{ kg A}}{\text{L A}} \right| = 143.105 \frac{\text{kg A}}{\text{hr}}$$

$$\frac{3 \text{ L C}}{\text{L B}} \left| \frac{29.86 \text{ L B}}{\text{hr}} \right| \left| \frac{1.0492 \text{ kg C}}{\text{L C}} \right| = 93.998 \frac{\text{kg C}}{\text{hr}}$$

42.209

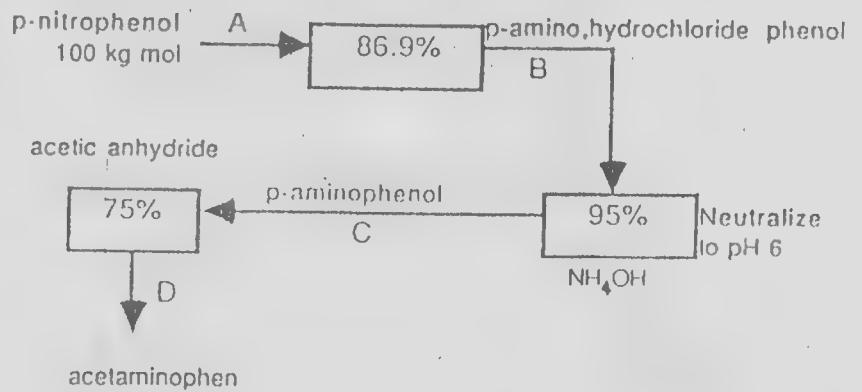
143.105

+ 93.998

 $\boxed{279.312 \text{ kg/hr}}$

(continued)

1.119

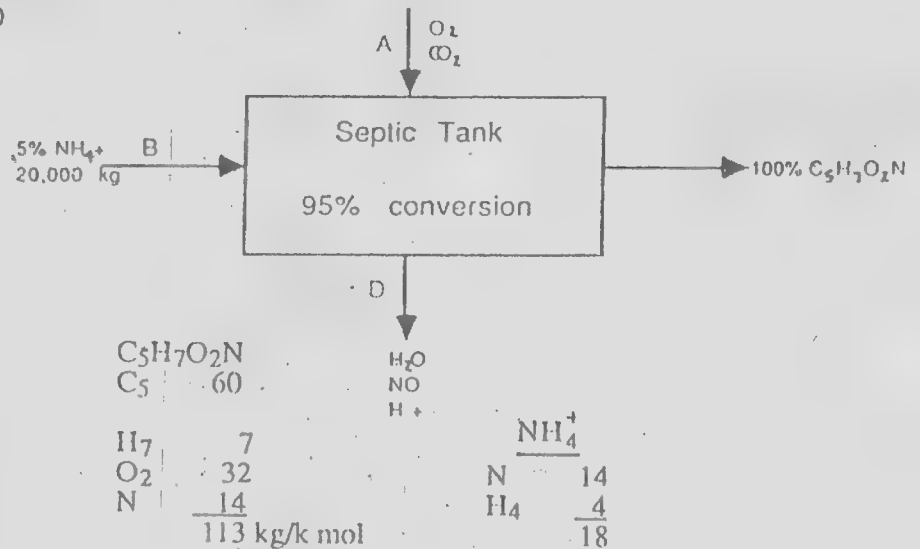


Basis: 100 kg mol A

$$\frac{100 \text{ kg mol } C_6H_5NO_2}{100 \text{ kg mol } C_6H_5NO_2} \left| \frac{86.9 \text{ kg mol } C_6H_8NOCl}{100 \text{ kg mol } C_6H_5NO_2} \right| \frac{0.95 \text{ kg mol } C_6H_7NO}{\text{kg mol } C_6H_8NOCl} \left| \frac{3 \text{ kg mol } C_8H_9NO_2}{4 \text{ kg mol } C_6H_7NO} \right|$$

→ [0.619 fraction overall conversion]

1.120



$$\frac{20,000 \text{ kg C}}{100 \text{ kg C}} \left| \frac{5 \text{ kg } NH_4^+}{100 \text{ kg C}} \right| = 1000 \text{ kg } NH_4^+$$

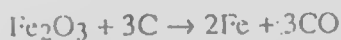
$$\frac{1000 \text{ kg } NH_4^+}{18 \text{ kg } NH_4^+} \left| \frac{\text{kg mol } NH_4^+}{18 \text{ kg } NH_4^+} \right| = 55.556 \text{ k mol } NH_4^+$$

(continued)

$$\frac{55.556 \text{ k mol NH}_4^+}{1 \text{ k mol C}_5\text{H}_7\text{O}_2\text{N}} \left| \frac{1 \text{ k mol C}_5\text{H}_7\text{O}_2\text{N}}{55 \text{ k mol NH}_4^+} \right| \frac{95 \text{ k mol NH}_4^+}{100 \text{ k mol fed}} \left| \frac{113 \text{ kg C}_5\text{H}_7\text{O}_2\text{N}}{\text{k mol C}_5\text{H}_7\text{O}_2\text{N}} \right|$$

$$= \boxed{108.43 \text{ kg C}_5\text{H}_7\text{O}_2\text{N}}$$

1.121 Reaction on which to base excess is



Basis: 1 ton Fe_2O_3

a. Theoretical C =

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{2000 \text{ lb Fe}_2\text{O}_3}{159.7 \text{ lb Fe}_2\text{O}_3} \right| \left| \frac{1 \text{ lb mol Fe}_2\text{O}_3}{1 \text{ lb mol Fe}_2\text{O}_3} \right| \left| \frac{3 \text{ lb mol C}}{1 \text{ lb mol Fe}_2\text{O}_3} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 451 \text{ lb}$$

$$\frac{600 - 451}{451} \times 100 = \boxed{33\% \text{ excess C}}$$

$$\text{b. } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{1 \text{ lb mol Fe}}{2 \text{ lb mol Fe}} \right| \left| \frac{1 \text{ lb mol Fe}_2\text{O}_3}{1 \text{ lb mol Fe}_2\text{O}_3} \right| \left| \frac{159.7 \text{ lb Fe}_2\text{O}_3}{1 \text{ lb mol Fe}_2\text{O}_3} \right|$$

= 1720 lb Fe_2O_3 reacts

$$\frac{1720}{2000} \times 100 = \boxed{86.0\% \text{ Fe}_2\text{O}_3}$$

$$\text{c. (i) } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{183 \text{ lb FeO}}{71.85 \text{ lb FeO}} \right| \left| \frac{1 \text{ lb mol FeO}}{2 \text{ lb mol FeO}} \right| \left| \frac{1 \text{ lb mol CO}}{1 \text{ lb mol CO}} \right| \left| \frac{28 \text{ lb CO}}{1 \text{ lb mol CO}} \right| = 35.62 \text{ lb CO}$$

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{1 \text{ lb mol Fe}}{2 \text{ lb mol Fe}} \right| \left| \frac{3 \text{ lb mol CO}}{1 \text{ lb mol CO}} \right| \left| \frac{28 \text{ lb CO}}{1 \text{ lb mol CO}} \right| = 902.4 \text{ lb CO}$$

$$\text{Total (35.62 lb CO + 902.4 lb CO)} = \boxed{938 \text{ lb CO}}$$

$$\text{(ii) } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{1 \text{ lb mol Fe}}{2 \text{ lb mol Fe}} \right| \left| \frac{3 \text{ lb mol C}}{1 \text{ lb mol C}} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 387.1 \text{ lb C}$$

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{183 \text{ lb FeO}}{71.85 \text{ lb FeO}} \right| \left| \frac{1 \text{ lb mol FeO}}{2 \text{ lb mol FeO}} \right| \left| \frac{1 \text{ lb mol C}}{1 \text{ lb mol C}} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 15.3 \text{ lb C}$$

$$387.1 + 15.3 = \boxed{402.4 \text{ lb C used / 1 ton Fe}_2\text{O}_3}$$

(continued)

$$\text{or use } \frac{938 \text{ lb CO}}{28 \text{ lb CO}} \times \frac{1 \text{ lb mol CO}}{1 \text{ lb mol CO}} \times \frac{1 \text{ lb mol C}}{1 \text{ lb mol CO}} \times \frac{12 \text{ lb C}}{1 \text{ lb mol C}}$$

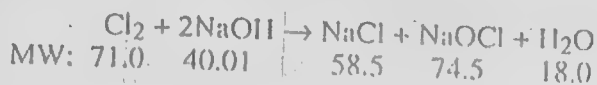
$$\text{d. Selectivity: Mass basis: } \frac{1200 \text{ lb Fe formed}}{183 \text{ lb FeO formed}} = 6.56$$

$$\frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} = 21.49 \text{ lb mol Fe}$$

$$183 \text{ lb FeO} \times \frac{1 \text{ lb mol FeO}}{71.85 \text{ lb FeO}} = 2.55 \text{ lb mol FeO}$$

$$\text{Mole Basis: } \frac{21.49 \text{ lb mol Fe}}{2.55 \text{ lb mol FeO}} = 8.44$$

1.122



$$\text{MW: } 71.0 \quad 40.01 \quad 58.5 \quad 74.5 \quad 18.0$$

$$\text{Basis: } 1145 \text{ lb}_m \text{ NaOH} + 851 \text{ lb Cl}_2 (\rightarrow 618 \text{ lb}_m \text{ NaOCl})$$

a. Determine limiting reactant

Assume all Cl_2 reacts, calculate lb of NaOH required

$$\text{NaOH required} = \frac{2 \text{ lb mol NaOH}}{1 \text{ lb mol Cl}_2} \times \frac{1 \text{ lb mol Cl}_2}{71 \text{ lb Cl}_2} \times \frac{851 \text{ lb Cl}_2}{1 \text{ lb mol NaOH}} \times \frac{40.01 \text{ lb NaOH}}{1 \text{ lb mol NaOH}}$$

$$= 959.11 \text{ lb NaOH required}$$

 $\therefore \text{Cl}_2$ is limiting reactant

$$\text{b. \% excess NaOH} = \frac{\text{lb mol NaOH in excess}}{\text{lb mol NaOH for rxn}} (100)$$

$$= \frac{\left(1145 \text{ lb}_m \text{ NaOH}\right) \left(\frac{1 \text{ lb mol NaOH}}{40.01 \text{ lb NaOH}}\right) - (959.11) \left(\frac{1}{40.01}\right)}{(959.11) \left(\frac{1}{40.01}\right)} (100)$$

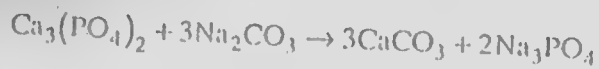
$$= 19.4\% \text{ excess NaOH}$$

$$\text{c. Degree of completion} = \frac{\text{lb mol NaOCl formed actual}}{\text{lb mol NaOCl formed for complete rxn}} = 0.692$$

$$\text{d. Yield of NaOCl} = \frac{618 \text{ lb NaOCl}}{851 \text{ lb Cl}_2} = 0.726$$

1.123 Basis: 500 kg $\text{Ca}_3(\text{PO}_4)_2$
500 kg Na_2CO_3

Na_2CO_3	kg	MW	kg mol
	500	106	4.72
$\text{Ca}_3(\text{PO}_4)_2$	500	312.6	1.60



a) Excess Reactant and % excess

Supplied: $\frac{\text{Na}_2\text{CO}_3}{\text{Ca}_3(\text{PO}_4)_2} = \frac{4.72}{1.60} = 2.95$

Required: $\frac{\text{Na}_2\text{CO}_3}{\text{Ca}_3(\text{PO}_4)_2} = \frac{3}{1}$ (stoichiometry).

Na_2CO_3 is the limiting reactant

$$\frac{\% \text{ Excess}}{1.60} = \frac{1.60 - 1.5}{1.60}$$

$\text{Ca}_3(\text{PO}_4)_2$ is the excess reactant

$$= 1.9\%$$

b) Degree of conversion of the limiting reactant = 40% (given)

c) Analysis of final product

	In (mol)	Consumed (mol)	Generated (mol)	Out (mol)
$\text{Ca}_3(\text{PO}_4)_2$	1.60	0.4(1.60)	0	0.96
Na_2CO_3	4.72	0.4(1.60)(3)	0	2.80
CaCO_3	0	0	0.4(1.60)(3)	1.92
Na_3PO_4	0	0	0.4(1.60)(2)	1.28

	Out (mole)	MW	Out (wt)	wt %
$\text{Ca}_3(\text{PO}_4)_2$	0.96	312.6	300	300
Na_2CO_3	2.80	106	297	297
CaCO_3	1.92	100.1	192	192
Na_3PO_4	1.28	164	210	211
			999	100

1.124 Basis: 1000 g filtrate

Comp.	%	g	MW	g mol
$(\text{NH}_4)_2\text{CO}_3$	0.5	5	114.11	0.052
$(\text{NH}_4)_2\text{SO}_4$	5.5	55	132.14	0.417
H_2O	94.0	940	18	52.222
	100.0	1000		

Basis: 1000 g filter cake

Comp.	%	g	MW	g mol
CaSO_4	8.2	92	172.18	0.476
CaCO_3	9.8	918	100.09	9.172
	100.0	100.0		

Reactants (g mol)

	NH_3	H_2O	CO_2	CaSO_4
for $(\text{NH}_4)_2\text{CO}_3$ unreacted	2(0.052)			
	=0.104	0.052	0.052	
for $(\text{NH}_4)_2\text{SO}_4$	2(0.417)			
	=0.834	0.417	0.417	0.417
for H_2O unreacted		52.222		
Unreacted CaSO_4				$0.417 \left(\frac{0.476 \text{ CaSO}_4}{9.172 \text{ CaCO}_3} \right)$
				=0.0216
Total	0.938	52.691	0.469	0.4387

Products (g mol)

$(\text{NH}_4)_2\text{CO}_3$	$(\text{NH}_4)_2\text{SO}_4$	CaCO_3	CaSO_4	H_2O
0.052	0.417	0.417	0.0216	52.222

Limiting reactant (ratio to CaSO_4)

Have:	NH_3	H_2O	CO_2	CaSO_4	By equation:	NH_3	H_2O	CO_2	CaSO_4
	$\frac{0.938}{0.938}$	$\frac{52.691}{0.4387}$	$\frac{0.469}{0.4387}$	$\frac{0.4387}{0.4387}$		$\frac{2}{1}$	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$

 $\boxed{\text{CaSO}_4}$

(continued)

b) degree of completion (fraction of limiting reactant that reacts)

$$\frac{\text{reacted}}{\text{available}} = \frac{0.417}{0.4387} = \boxed{0.95}$$

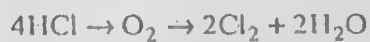
c) % excess reactant

$$\text{NH}_3 \quad \frac{.938 - 0.417(2)}{0.417(2)} \times 100 = \boxed{12.5\%}$$

$$\text{CO}_2 \quad \frac{.469 - .417}{0.417} \times 100 = \boxed{12.5\%}$$

$$\text{H}_2\text{O} \quad \frac{56.691 - .417}{0.417} \times 100 = \boxed{125\%}$$

1.125



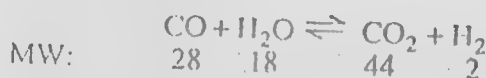
	% mol		entering moles	
HCl	4.4		HCl	O ₂
Cl ₂	19.8		4.4	4.0
H ₂ O	19.8	2 × 19.8 =	39.6	$\frac{19.8}{2} = 9.9$
O ₂	4.0		44.0	13.9
N ₂	52.0			
	100			

a) $\therefore$ HCl is the limiting reactant

$$\text{b) } \% \text{ excess} = \frac{13.9 - \frac{44.0}{4}}{\frac{44.0}{4}} \times 100 = \boxed{26.36\%}$$

$$\text{c) } \% \text{ completion} = \frac{44 - 4.4}{44} \times 100 = \boxed{90\%}$$

1.126 Basis: 30 mol CO, 12 mol CO₂, 35 mol H₂O feed ≈ 1 hr



a) $\frac{\text{fed CO}}{\text{H}_2\text{O}} = \frac{30}{35} = 0.86 < \frac{\text{in eqn CO}}{\text{H}_2\text{O}} = \frac{1}{1} = 1$

CO is limiting reactant

b) H₂O is the excess reactant

c) $\frac{18}{35} = 0.514$

d) $\frac{18}{30} = 0.60$ (for each mol of H₂ produced, 1 mol CO reacts)

e) $\frac{18 \text{ kg mol H}_2}{1 \text{ kg mol H}_2} \times \frac{2.016 \text{ kg H}_2}{35 \text{ kg mol H}_2\text{O}} \times \frac{1 \text{ kg mol H}_2\text{O}}{18 \text{ kg H}_2\text{O}}$
 $= 0.0576 \text{ kg H}_2$

f) 1 mol of CO₂ is produced for each mol of H₂

$\frac{18}{30} = 0.60 \frac{\text{mol CO}_2}{\text{mol CO}}$

2.1	It's possible with a broken hydrometer. It's time to buy a new one.
2.2	It depends on what the problem is. Does "greater" refer to volume, number, mass, value, or?
2.3	The same middle name (the)
2.4	They differ because additional information (engineering knowledge) is required to relate the mathematical statement to the actual application. You can say that the units associated with the numbers make the difference in the real world. While 2 kg of water + 2 kg alcohol = 4 kg solution, 2 cm^3 of water + 2 cm^3 of alcohol $\neq 4 \text{ cm}^3$ of mixture.
2.5	Possible options are largest area pen, longest pen (to permit running), closest to house that will form one side, etc.
2.6	Apply the propagation of error relation to the dynamic equations from physics. Or, consider a combinatorial set of cases for deviations of measurements (high and low from accurate), and predict the deviation in landing for each case. Interaction (multiple errors) have to be included in the analysis.
2.7	Morpholine has an autoignition temperature of 590°F (apparently what the fire chief was thinking of). In Hawley's Chemical Dictionary, morpholine is listed as a moderate fire risk.
2.8	Jacobs is a optics professor. Kim caught him in front of the stove next to the bucket of oil. Remembering her physics, Kim figured out that crystal has the same index of refraction as cooking oil. Therefore, when Jacobs dropped the vase in the oil, it became invisible. The options to choose from by the K-T method were all of the individuals involved in the case description. The constraints were motive, timing, opportunity, knowledge, observed (reported) taking the vase, size of the vase, admission of guilt.
2.9	What Kim noticed was the Al_2O_3 covering the lab surfaces. Al reacts with NH_4NO_3 to produce Al_2O_3 , H_2O , and N_2 so that the only product remaining from the fire would be a powder. After easily breadking open one of the old gas lines near the hood, the culprit left the bomb on the main counter. The bomb ignited the escaping natural gas and BOOM! Due to Detective Stone's comment about the students' opinion of the professor and the attitude of the professor himself, Kim suspects it was a student who planned the bomb.

- 2.10 An explanation of the process (our hypothesis) is
1. As temperature rises, water inside the kernel becomes steam
 2. Trapped steam exerts an increasing pressure on the hull
 3. The hull tears at its weakest point
 4. Escaping steam expands out the hole
 - a. pushing the contents out and fluffing them
 - b. inverting the hull
 - c. pushing the kernel in the opposite direction.

Possible tests of this model are:

1. Is the condensate water?
2. Does the mass of a kernel decrease after popping?
3. Is the mass of the water lost (recover by trapping) equal to the mass lost by the kernel? (Briefly discuss the conservation of mass). How does the odor detected fit into this?
4. Does drilling a hole in the kernel prevent popping? Are the kernels which did not pop cracked or broken?
5. Will kernels pop at less than 100°C?
6. Will they pop in a pressure cooker? (Discuss how a pressure cooker works, and note that water is added to produce the steam).
7. Can the popping process be captured by high-speed photography?
8. Can we cut a kernel in half and see the structure?

Other questions:

- (1) Is the necessary air stored inside the kernel? The high density implies little free air is present, and the known long lives of seeds (months to decades) render it unlikely that enough could be present. The required air probably comes from the atmosphere.
- (2) Is there a one-way trap door that allows gases in but not out? Since the net reaction involved is



this implies a buildup of CO_2 inside the kernel and eventual popping without heat.

- (3) Is there a hole small enough to let oxygen in but not steam out? An oxygen molecule is nearly twice the size of a water molecule.
- (4) Does heating cause the hole(s) present in the kernel to swell shut, allowing steam pressure to build up?
- (5) Is there a small hole that allows oxygen to enter slowly but cannot vent the rapid steam build-up?

- 2.11 Some methods might be (1) acoustic emissions (created by cracks) -- nondestructive, sensitive, passive, but must interpret signatures; weak signal, inconsistent; (2) portable flame ionization detectors (cheap, portable, but must move to site, requires manpower); (3) examine fluid turbidity; and many more options.

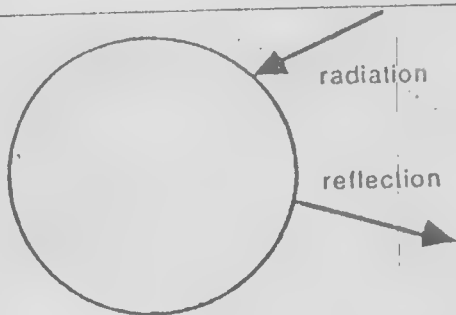
- 2.12 For a brief but thorough explanation refer to *Nature*, Vol. 351, 1991, p. 304.

2.13 Only one material flowing, steam. The answers for the base case are:

$x_3 = 20.684$	$x_{10} = 0$
$x_4 = 2.906$	$x_{11} = 11.562$
$x_5 = 20.339$	$x_{12} = 27.957$
$x_6 = 24.200$	$x_{13} = 8.045$
$x_7 = 95.801$	$x_{14} = 290.556$
$x_8 = 2.421$	$x_{15} = 0$
$x_9 = 14.619$	$x_{16} = 164.70$

- 2.15 a. $x_1 = 1, x_2 = 3, x_3 = -3$
 b. $x_1 = x_2 = x_3 = 0$
 c. $x_1 = 1, x_2 = 3, x_3 = 1$
 d. multiple solutions exist

2.16.



Need an energy balance that accounts for radiation from sun, and reflection to space. The independent variable would be temperature and the dependent variable would be time. Need to relate the reception and loss of energy to temperatures that are known, or rates of energy transfer that are known, from the sun and to outer space.

- 2.17 1. 3.82 g/cm^3
 2. $305 - 309^\circ\text{C}$
 3. $8 \text{ g/100 g H}_2\text{O}$
 4. $24.00 \text{ ft}^3/\text{lb}$

2.18 Yes; Yes; Yes.

- 2.19 Examples: (1) J. of Chemical and Engineering Data
 (2) Chemical Reviews
 (3) J. Chem. Physics
 (4) J. Inst. Sids. Technol.

3.1

Basis: Data shown on flowsheet units are MTA

In	Out
2.5×10^6	404×10^3
	228×10^3
	152×10^3
	101×10^3
	67×10^3
	36×10^3
	100×10^3
	1190×10^2
	$2,278 \times 10^3$

mass in does not equal to mass out.

Reasons:

- (1) Some of the material was burned as fuel
- (2) Some of the material formed gases that were exhausted to atmosphere (such as H_2O , CO_2).
- (3) errors in measurement.

3.2

- a) closed
- b) open
- c) open
- d) closed

3.3

If a reaction occurs, some of the entering moles will be used up, and new ones produced that exit but did not enter.

3.4

Any reasonable examples are acceptable.

Solutions. - Chapter - 3

3.5

Boundary: Around pumps and soil at the end of the pipes. Use the box outlining the process but extend the vacuum pump to the edge of the box.

It's an open system.

It's at steady-state except at startup (note system boundary limits fluid), or if fluid enters, unsteady state.

3.6

$$\text{Volume of Plume: } \frac{1 \text{ mile} \left| \frac{5280 \text{ ft}}{1 \text{ mile}} \right| \frac{30 \times 200 \text{ ft}^2}{35.31 \text{ ft}^3}}{1 \text{ mile}} = 8.974 \times 10^5 \text{ m}^3$$

$$\text{Mass of isocyanate: } \frac{100 \text{ lb} \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \frac{10^3 \text{ mg}}{1 \text{ g}}}{1 \text{ lb}} = 454 \times 10^5 \text{ mg}$$

$$\frac{454 \text{ mg}}{8.974 \text{ m}^3} = \boxed{50.5 \text{ mg/m}^3}$$

Therefore, the concentration of plume exceeds 47 mg/m^3

3.7

The system is the radiator.

	<u>Open System</u>	<u>Closed System</u>	<u>Steady-State</u>	<u>Unsteady State</u>
a)	X			X
b)	X			X
c)	X (Before filling)	X (After filling)	X (After filling)	X (Before Filling)
d)	X	X*	X	X*

* depending on whether an overflow reservoir exists that is not part of system.

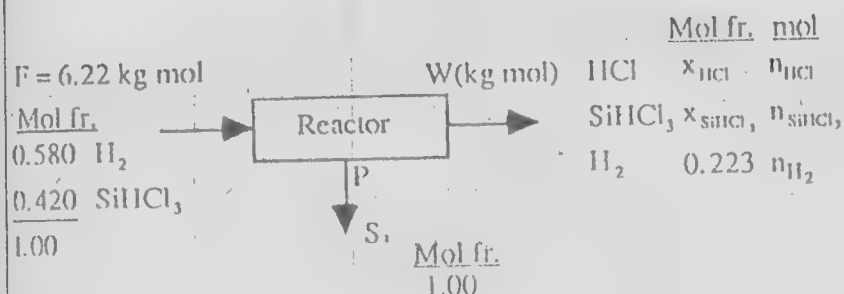
3.8

Assume a steady state flow process with reaction.

Step 5: Basis: 1 hr ($6.22 \text{ kg mol} = F$)

(continued)

Steps 1, 2, 3 and 4:



$$\text{MW Si} = 28.086$$

$$n_{\text{H}_2}/W = 0.223$$

Step 6:

Unknown: $W, P, 3n_i$

Step 7:

Balances: element balances are H, Si, Cl, $\sum n_i = W$, $n_{\text{H}_2}/W = 0$

Steps 8 and 9:

H and Cl are in the components. Balances are in kg mol.

$$\text{Cl (kg mol):} \quad \frac{\text{In}}{6.22(0.420)(3)} = \frac{\text{Out}}{n_{\text{HCl}} + n_{\text{SiHCl}_3}(3)}$$

$$\text{Si (kg mol):} \quad 6.22(0.420)(1) = P(1) + n_{\text{SiHCl}_3}$$

$$\text{H (kg mol):} \quad 6.22[(0.580)(2) + 0.420(1)] = n_{\text{HCl}} + n_{\text{SiHCl}_3} + n_{\text{H}_2}(2)$$

Solution:

$$W = 8.05 \quad P = 1.83$$

$$n_{\text{H}_2} = 1.78 \quad n_{\text{HCl}} = 5.49 \quad n_{\text{SiHCl}_3} = 0.7824$$

$$\frac{1.83 \text{ kg mol Si}}{1 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{20 \text{ min}}{1} \times \frac{28.086 \text{ kg Si}}{1 \text{ kg mol Si}} = 17.13 \text{ kg Si}$$

$$\frac{1.46 \text{ kg Si initial}}{18.59 \text{ kg final Si}}$$

3.9

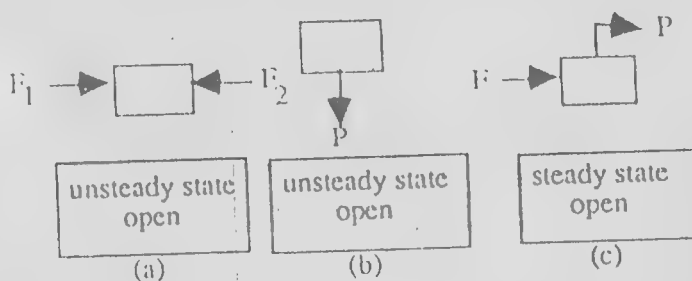
Basis: 1 week

$$\text{in (tons)} = 920 + 0.6 = 920.6$$

$$\text{out (tons)} = 3.8 + 620 + 0.01 + 0.01 + 0.08 + 1.1 + 275 + 20 = 920$$

Yes

3.10



3.11

(a)

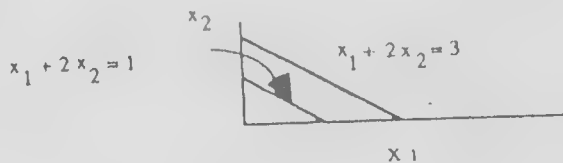
The rank of the coefficient matrix is only 1 because the

$$\det \begin{bmatrix} 1 & 2 \\ 1 & 2 \end{bmatrix} = 0$$

The rank of the augmented matrix is 2

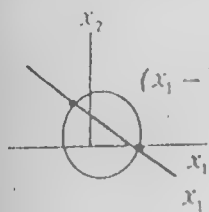
Largest non zero det. of $\begin{bmatrix} 1 & 2 & 1 \\ 1 & 2 & 3 \end{bmatrix}$ is of order 2

Thus, although the 2 equations are independent and the number of variables is 2 (the necessary conditions), the sufficient conditions are not met.



(continued)

(b)



$$(x_1 - 1)^2 + (x_2 - 1)^2 = 0$$

No; 2 solutions

The equations are independent

$$x_1 + x_2 = 1$$

The number of variables whose values are unknown is 3. The number of independent equations is 2 because the rank of the coefficient matrix is 2.

$$\det \begin{bmatrix} 1 & 2 & -3 \\ 3 & -1 & 2 \\ 5 & 3 & -4 \end{bmatrix} = 0$$

$$1(4-6) - 3(-8+9) + 5(4-3) = 0$$

3.12

(a) $\Lambda \rightarrow \begin{bmatrix} 1 & 3 & 3 & 2 \\ 0 & 0 & 3 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ so rank is 2

(b) $|\Lambda| = 0$ and $\begin{vmatrix} 1 & 2 \\ 2 & 3 \end{vmatrix} = -1$ so rank is 2

(c) $\text{del } |\Lambda| = -1$ so rank is 3

3.13

a) $\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 3 \\ 3 & 5 & 7 \end{bmatrix}$ rank of coefficient matrix is 2.
rank of augmented matrix is 2.

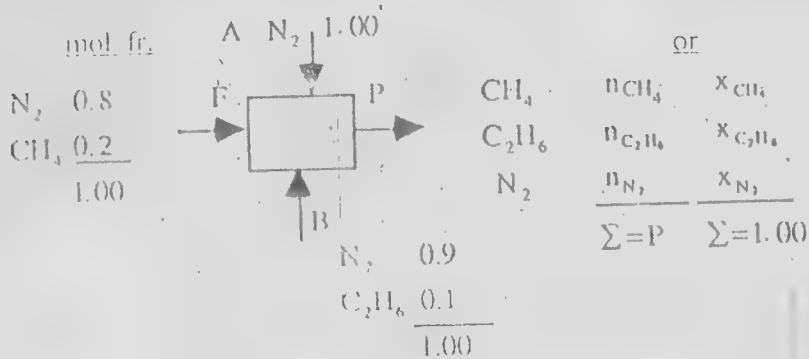
$$r = 2, n = 3 \quad \text{multiple solutions exist}$$

b) $\begin{bmatrix} 1 & 0 & 1 \\ 5 & 4 & 9 \\ 2 & 4 & 6 \end{bmatrix}$ 3d column is sum of 1st two columns, so rank is 2.
rank of augmented matrix is 2, also.

$$r = 2, n = 3 \quad \text{multiple solutions exist}$$

3.14 The number of independent equations is just 3. The number of unknown quantities is 3, hence a unique solution is possible.

3.15



Unknown variables

Balances*

n_{CH_4} x_{CH_4}

$n_{C_2H_6}$ or $x_{C_2H_6}$

n_{N_2} x_{N_2}

N_2

CH_4

C_2H_6

If use mol. fr., $\Sigma x_i = 1$ in P

Otherwise, $\Sigma n_i = P$

$\frac{n_{CH_4}}{n_{C_2H_6}} = 1.5$

A

B

F

P

Total Count: (6) or (7)

(4)

(5)

deg. freedom are $6 - 4 = 2$ or $7 - 5 = 2$ or 1 if select a basis

* can use C, H, N as alternates

3.16

$$F_1 + F_2 + F_3 = P$$

Only 3 equations are independent.

Four balances are possible, 3 component plus 1 total.

$$0.10F_1 + 0.50F_2 + 0.20F_3 = 0.35P$$

$$0.20F_1 + 0F_2 + 0.30F_3 = 0.10P$$

$$0.70F_1 + 0.50F_2 + 0.50F_3 = 0.55P$$

3.17

If specify F, P, W, you can calculate all of the stream variables.

- a) Unknown: three stream values F, P, W
- b) The two known compositions are not given but may be calculated,
0 hence should not be treated as unknowns unless extra equations are added for the summation of mole fractions.
- c) Two components exist, hence two independent material balances can be written. The problem cannot be solved unless one stream value is selected as a basis.

3.18

There are 3 streams, 9 compositions and 3 flows = 12, but one composition is $x_{nw} = 0$, and three of the compositions can be determined by difference, i.e., using the summation of mole fractions relation, hence the unknowns are $12 - 1 - 3 = \underline{8}$.

There are 3 components, hence maximum of 3 independent material balances can be written. Thus 5 measurements must be made. Or calculate $12 - 1 = 11$ and $11 - 6 = 5$ if the Σx_i are considered to be equations.

You cannot use all the flows, or all the compositions in one stream as the resulting set of material balances will not consist of 5 independent balances, but a lesser number.

3.19

You can see by inspection that no combination of tanks 1, 2 and 3 will give a mole fraction of 0.52 for the mixture.

Basis: 2.50 mol of tank 4

Let x_i = be the total moles of tank i

The balances are

$$\begin{aligned} 0.23x_1 + 0.20x_2 + 0.64x_3 &= 0.25(2.5) = 0.625 \\ 0.36x_1 + 0.33x_2 + 0.27x_3 &= 0.23(2.5) = 0.575 \\ 0.41x_1 + 0.47x_2 + 0.19x_3 &= 0.52(2.5) = 1.300 \end{aligned}$$

The coefficient matrix has a rank of 3 as does the augmented matrix so the set of equations has a solution. However, the solution is

$$\begin{aligned} x_1 &= -4.00 \\ x_2 &= 6.36 \\ x_3 &= -0.327 \end{aligned}$$

The values of x_1 and x_3 are not physically realizable!

20

Basis: D=100 lb

 x_1 x_2 x_3

Coefficient matrix is

3 by 3 for 1st 3 rows

0.5	0	0	1	1.4
90.0	10.0	0	1	31.2
5.0	85.0	8.0	1	53.4
0	5.0	80	1	12.6

No unique solution exists with 5 equations and 3 variables. A least squares solution could be determined or the 3 equations with the most accurate data solved. You can see that if you solve the last 3 equations formed from the last 3 rows and substitute the answer into the equation formed from the second row, the equation does not balance. More formally

The rank of the coefficient matrix is 3

The rank of the augmented matrix is 4 or 5

Hence no unique solution exists.

21

Up to 5 compound mass balances can be made. In each stream, the $\sum \omega_i = 1$ or $\sum n_i =$ stream value, and one mass (or mass fraction) can be solved for each stream.

The total number of variables whose values are unknown is: 10 concentrations and 4 streams, and the number of balances is:

One set of measurements could be to measure concentrations.

A: HNO_3 , H_2SO_4 , (H_2O obtained by difference from 1)B: H_2SO_4 (H_2O obtained by difference from 1)

C: Nothing needed.

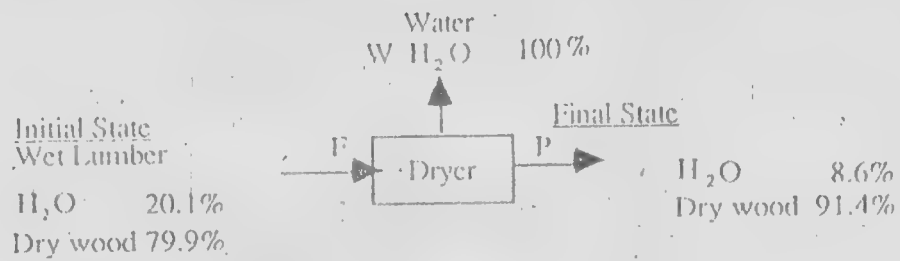
D: Nothing needed.

E: CaSO_4

Let A, B, C, D and one composition in E be unknown.

Specifications required: $14 - 10 = 4$.b) NO

3.22



Basis: 100 kg entering wet wood

All units are mass.

1. Unknowns: F, P, W, but if pick $F = 100$ kg as a basis, only W, and P are unknown.
2. Two independent equations can be written, H_2O and dry wood.
3. Yes

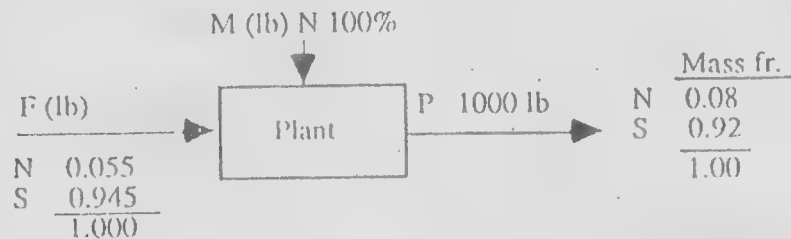
3.23

Examine the row of C_3H_8 . None of the concentrations are greater than the desired 50% so 50% is not achievable by any combination of A, B, or C.

3.24

Steps 1, 2, 3 and 4:

Treat the problem as a steady state flow problem, or as an unsteady state batch system.



Step 5: Basis: 1000 lb P

Steps 6 and 7: Two unknowns, F and M. Two balances can be made, N and S.

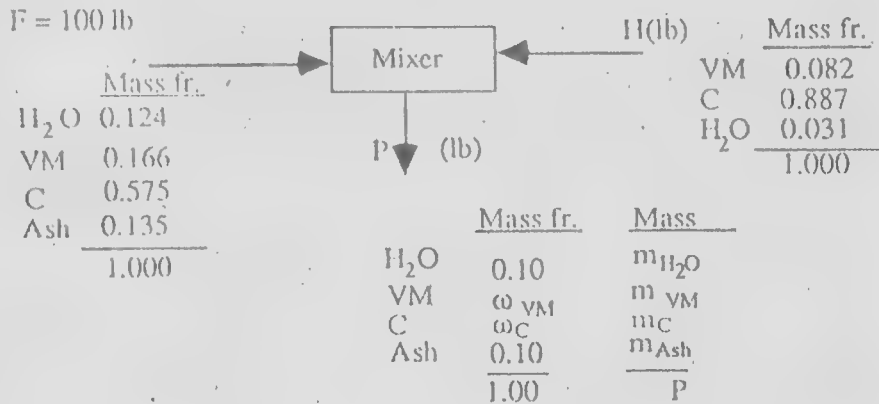
(continued)

Solve to get

Steps 8 and 9: N: $F(0.055) + M(1.00) = 1000(0.008)$ } $F = 973.5 \text{ lb}$
 S: $F(9.045) + M(0) = 1000(0.92)$ } $M = 26.5 \text{ lb}$
 $P = 1000.0 \text{ lb}$

3.25

Steps 1, 2, 3, and 4:



Step 5: Basis: $F = 100 \text{ lb}$

Step 6: Unknowns: $m_{\text{H}_2\text{O}}, m_{\text{VM}}, m_{\text{C}}, m_{\text{Ash}}, P, H$ (6)

Step 7: Balances: $\text{H}_2\text{O}, \text{VM}, \text{C}, \text{Ash}, \sum m_i = P, m_{\text{H}_2\text{O}}/P = 0.10$
 $m_{\text{Ash}}/P = 0.10$ (7) and presumably 6 are independent

Steps 8 and 9:

	In	=	Out
$\text{H}_2\text{O}(\text{lb})$:	$100(0.124) + H(0.082)$	=	$m_{\text{H}_2\text{O}}$
VM (lb)	$100(0.166) + H(0.082)$	=	m_{VM}
C (lb):	$100(0.575) + H(0.887)$	=	m_{C}
Ash (lb)	$100(0.135) + H(0)$	=	m_{Ash}
Total	$100 + H$	=	P

Solution:

$m_{\text{Ash}} = 13.5 \text{ lb}$

$m_{\text{H}_2\text{O}} = 13.516$

(continued)

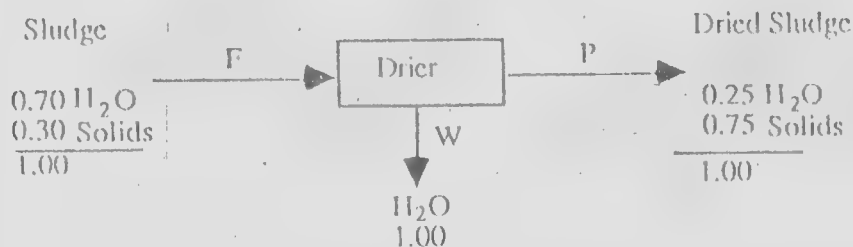
$$P = \frac{m_{\text{Ash}}}{0.10} = 135 \text{ lb}$$

$$H = 135 - 100 = 35 \text{ lb}$$

Step 10: Check via H_2O balance

$$\begin{array}{rcl} 12.4 + 35(0.031) & = & 13.5 \\ 13.49 & = & 13.5 \end{array} \quad \left. \vphantom{\begin{array}{rcl} 12.4 + 35(0.031) & = & 13.5 \\ 13.49 & = & 13.5 \end{array}} \right\} \text{yes}$$

3.26



Basis: 2000 lb F

Balances: H_2O , Solids

Unknowns: P, W

Total: $2000 = P + W$

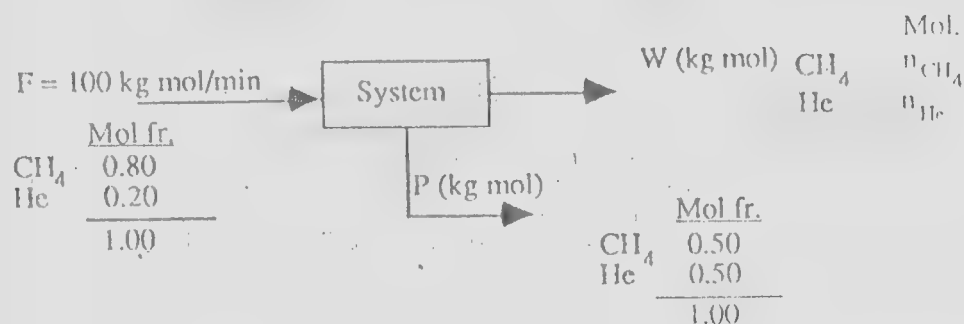
Solids: $2000(0.30) = P(0.75)$

$$P = 800 \text{ lb}$$

$$W = 2000 - 800 = 1200 \text{ lb}$$

3.27

Steps 1, 2, 3 and 4:



Step 5:

Basis: 1 min → 100 kg mol F

(continued)

Solutions - Chapter - 3

Step 4: To get P, calculate first the average mol. wt. of F
Basis: 1.00 mol F

	Mol	MW	kg
CH ₄	0.80	16.03	12.8
He	0.20	4	0.8
	1.00		13.6

	Mol	MW	kg
CH ₄	0.50	16.03	8.01
He	0.50	4	2.0
	1.00		10.01

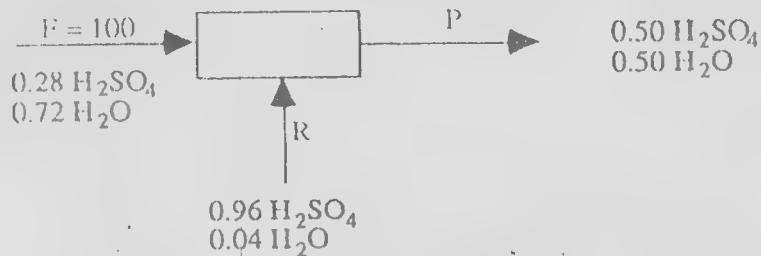
100 kg mol F	13.6 kg F	0.20 kg P	1 kg mol P
	1.00 kg mol F	1 kg F	10.01 kg P

$$P = 27.2 \text{ kg mol}$$

Steps 6, 7, 8 and 9:

		Mol	In W	Mol.fr.
$100(0.80) = 27.2(0.50) + n_{\text{CH}_4}$	n_{CH_4}	66.4		0.912
$100(0.20) = 27.2(0.50) + n_{\text{He}}$	n_{He}	6.4		0.088
		72.8		1.00

3.28



Unknowns: P, R; Balances: (H₂O, H₂SO₄) = 2

	dilute (%)	conc. (%)	mixed (%)
H ₂ SO ₄	28	96	50
H ₂ O	72	4	50
	100	100	100

Basis: 100 kg dilute acid (28% H₂SO₄)
(continued)

Sulfuric acid balance:

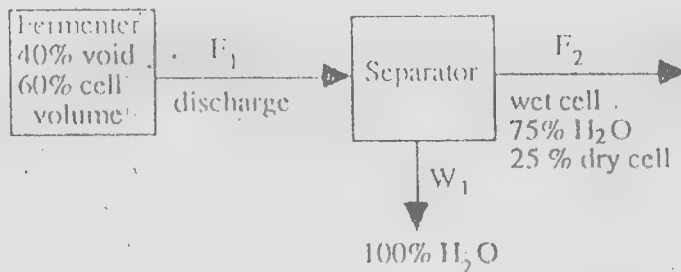
$$(100)(0.28) + R(0.96) = (100 + R)(0.50)$$

$$(0.96 - 0.50)R = (0.50 - 0.28)(100)$$

$$\frac{R}{100} = \frac{0.50 - 0.28}{0.96 - 0.50} = 0.478$$

$$R = (0.478)(100) = \boxed{47.8 \text{ kg conc. acid} / 100 \text{ kg dilute acid}}$$

3.29

Basis: $1000 \text{ cm}^3 \cdot F_1$

$$\text{Dry cells} = \frac{1000 \text{ cm}^3 \text{ in fermenter}}{100 \text{ cm}^3 \text{ in fermenter}} \left| \frac{60 \text{ cm}^3 \text{ cell}}{1 \text{ cm}^3 \text{ cell}} \right| \left| \frac{1.1 \text{ g cell}}{100 \text{ g cell}} \right| \left| \frac{25 \text{ g solids}}{100 \text{ g cell}} \right|$$

$$= \boxed{16.5 \text{ g Dry cell} / 1000 \text{ cm}^3 \text{ in fermenter}}$$

3.30

Basis: 100 lb wet casein

Comp.	lb wet	dried, % = lb
H ₂ O	23.7	.10
casein	76.3	.90
	100.0	100

$$\frac{76.3 \text{ lb dry casein}}{90 \text{ lb dry casein}} \left| \frac{100 \text{ lb total}}{100 \text{ lb dry casein}} \right| = 84.7 \text{ lb dry casein}$$

$$100 - 84.7 = 15.3 \text{ lb H}_2\text{O removed}$$

$$\frac{(15.3)(0.80)}{(100)} = \$0.122 \text{ cost of drying}$$

(continued)

$$8.00 + 0.122 = \$8.122 \text{ cost of dried casein}$$

$$\frac{(8.122)(100)}{(84.7)}$$

$$= \$9.58 \text{ per 100 lb dried casein selling price}$$

3.31

a. Basis: 1 kg mole of mixture

Three components exist: $(\text{CH}_4)_x$, $(\text{C}_2\text{H}_6)_x$, $(\text{C}_3\text{H}_8)_x$

Let A, B, C respectively represent kg mol of each mixture; these are the unknowns.

Equations:

$$0.25A + 0.35B + 0.55C + 0.30 = (\text{CH}_4)_x \text{ balance}$$

$$0.35A + 0.20B + 0.40C + 0.30 = (\text{C}_2\text{H}_6)_x \text{ balance}$$

$$0.40A + 0.45B + 0.05C + 0.40 = (\text{C}_3\text{H}_8)_x \text{ balance}$$

Det of the coefficient matrix

$$\begin{bmatrix} 0.25 & 0.35 & 0.55 \\ 0.35 & 0.20 & 0.40 \\ 0.40 & 0.45 & 0.05 \end{bmatrix} = 0.0500 \quad \text{Rank} = 3$$

Augmented matrix

$$\begin{bmatrix} 0.25 & 0.35 & 0.55 & 0.30 \\ 0.35 & 0.20 & 0.40 & 0.30 \\ 0.40 & 0.45 & 0.05 & 0.40 \end{bmatrix} \quad \text{Rank} = 3$$

Since ranks are same and = 3, there is a unique solution to the set of equations (in kg mol)

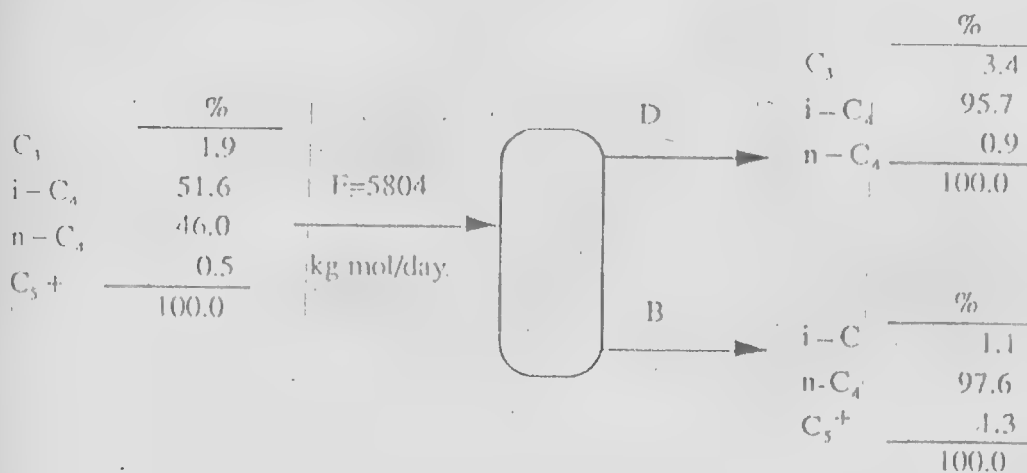
$$A = 0.600 \quad B = 0.350 \quad C = 0.005$$

b. It is proposed to prepare the final mixture by blending four different compounds (A, B, C, D); there will still be three equations, but now there will be four unknowns. Since the rank is now less than n, there will be an infinite number of possible blends of the four mixtures. Not required: (An optimization of a revenue function subject to the equations is needed.)

Solutions - Chapter - 3

3.32

Basis: 1 day



	In		Out
C_3	$(0.019)(5804) = 110$	=	$0.034D$
$i-C_4$	2992	=	$0.957D + 0.011B$
$n-C_4$	2667	=	$0.009D + 0.976B$
C_5^+	37	=	$0.013B$
Total:	5804	=	$D + B$

We have 4 independent equations, but the precision of measurement is not the same in each equation, hence different results are obtained depending on the equations used.

Use total + $i-C_4$ balances:

$$2992 = 0.975(5804 - B) + 0.011B$$

kg mol/day

$$B = 2563$$

$$D = 3240$$

Use total + $n-C_4$ balances:

$$2667 = 0.009(5804 - B) + 0.976B$$

$$B = 2704$$

$$D = 3100$$

C_3 as a tie component:

$$\frac{5804 \text{ kg mol F}}{1 \text{ day}} \left| \frac{0.019 \text{ kg mol } C_3}{1.00 \text{ kg mol F}} \right| \frac{1 \text{ kg mol D}}{0.034 \text{ kg mol } C_3} = 3243 \frac{\text{kg mol D}}{\text{day}}$$

C_5^+ as a tie element:

$$\frac{5804 \text{ kg mol F}}{1 \text{ day}} \left| \frac{0.006 \text{ kg mol } C_5^+}{1.00 \text{ kg mol F}} \right| \frac{1 \text{ kg mol B}}{0.013 \text{ kg mol } C_5^+} = 2679 \text{ kg mol B / day}$$

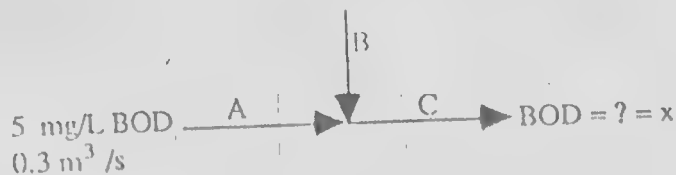
3.33

Steps 1, 2, 3, and 4:

a.

$$3.785 \times 10^6 \text{ L/day}$$

$$150 \text{ mg/L BOD}$$



Step 5: Basis: 1 day

$$A = \frac{0.3 \text{ m}^3}{\text{s}} \left| \frac{3600 \text{ s}}{\text{hr}} \right| \left| \frac{24 \text{ hr}}{\text{day}} \right| \left| \frac{1000 \text{ L}}{\text{m}^3} \right| = 2.592 \times 10^7 \text{ L/day}$$

Steps 6 and 7:

Unknowns: C, x

Balances: H₂O, BOD

Steps 8 and 9:

Total mass balances

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg B}}{\text{L}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg C}}{\text{L}} \right|$$

BOD mass balance

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{5 \times 10^{-3} \text{ g BOD}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{150 \times 10^{-3} \text{ g BOD}}{\text{day}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{x \text{ g BOD}}{\text{L}} \right|$$

$$A + B = C$$

$$2.592 \times 10^7 \text{ kg} + 3.785 \times 10^6 \text{ kg} = C = 2.9705 \times 10^7 \text{ kg}$$

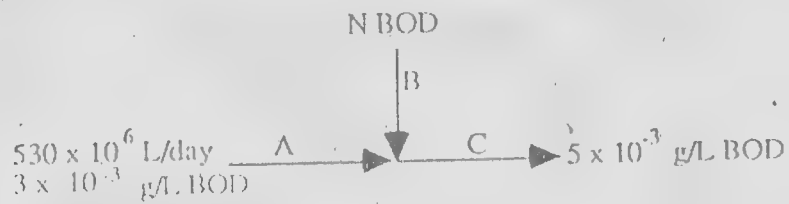
$$5 \times 10^{-3} A + 150 \times 10^{-3} B = xC$$

$$x = \frac{5 \times 10^{-3} A + 150 \times 10^{-3} B}{C}$$

$$= \frac{5 \times 10^{-3} (2.592 \times 10^7) + 150 \times 10^{-3} (3.785 \times 10^6)}{2.9705 \times 10^7} = \boxed{23.475 \times 10^{-3} \text{ g/L}}$$

(continued)

b.

Total mass balance

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg}}{\text{L}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg}}{\text{L}} \right|$$

$$A + B = C$$

$$530 \times 10^6 \text{ kg} + 15.8 \times 10^6 \text{ kg} = C = 5.458 \times 10^8 \text{ kg}$$

BOD mass Balance

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{3 \times 10^{-3} \text{ g BOD}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{N \times 10^{-3} \text{ g}}{\text{L}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{5 \times 10^{-3} \text{ g}}{\text{L}} \right|$$

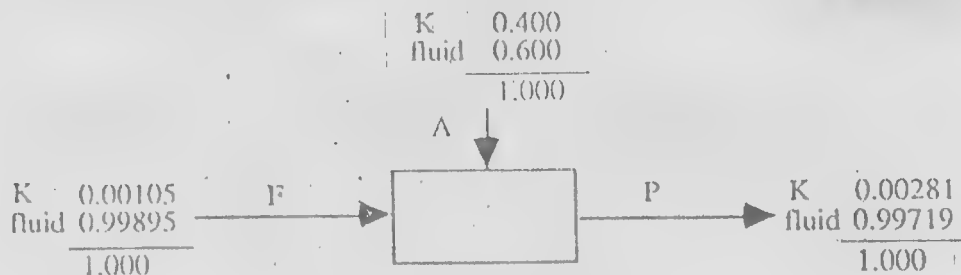
$$3 \times 10^{-3} A + N \times 10^{-3} B = 5 \times 10^{-3} C$$

$$N = \frac{5 \times 10^{-3} C - 3 \times 10^{-3} A}{B}$$

$$= \frac{(5 \times 10^{-3})(5.458 \times 10^8) - (3 \times 10^{-3})(5.30 \times 10^8)}{1.58 \times 10^7} \boxed{\cong 72.1 \times 10^{-3} \text{ g/L}}$$

3.34

Steps 1, 2, 3, and 4:

Step 5: Basis: 1 min ($K = 0.400$ kg)Step 6: Unknowns: F, P Step 7: Balances: K, fluid

Steps 8 and 9:

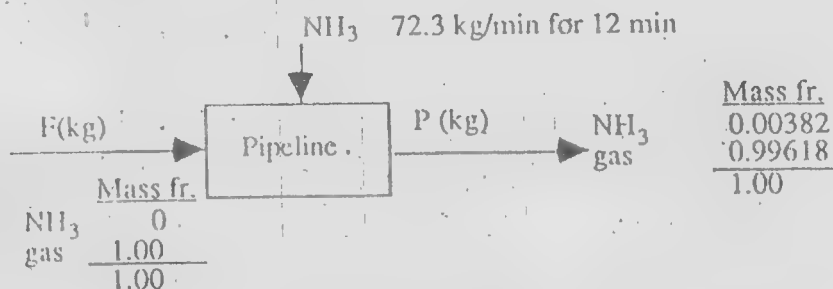
$$K: F(0.00105) + 0.4 = P(0.00281)$$

$$F \equiv P = 227 \text{ kg/min}$$

$$\text{fluid: } F(0.99895) + 0.6 = P(0.99719)$$

3.35

Steps 1, 2, 3, and 4:



Step 5: Basis: 1 min

Steps 6 and 7: Two unknown, F and P . Two balances can be made, NH_3 and gas. You can use the total balance as a substitute.

Steps 8 and 9:

$$\text{Total: } F + 72.3 = P$$

$$\text{NH}_3: F(0) + 72.3 = P(0.00382)$$

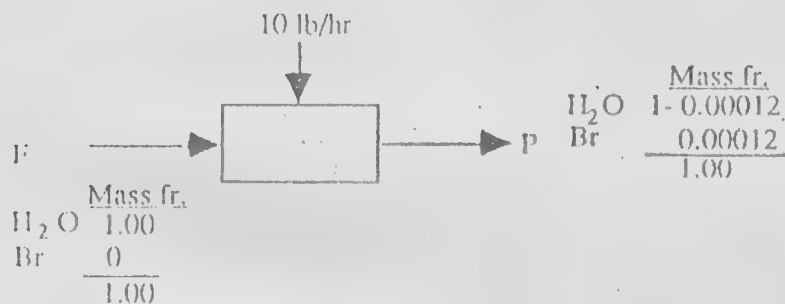
$$P = 18,900 \text{ kg/min}$$

$$F = 18,900 \text{ kg/min or } 1.14 \times 10^6 \text{ kg/hr}$$

Step 10: Check using the gas balance

3.36

Steps 1, 2, 3, and 4:



Step 5: Basis: 1 hr

Step 6: Unknowns: F, P

Step 7: Balances: H₂O, Br

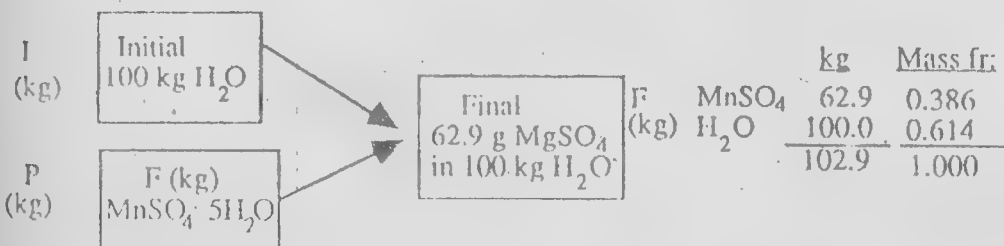
Steps 8 and 9:

$$\begin{array}{lcl}
 \text{Total:} & F + 10 & = P \\
 \text{Br:} & F(0) + 10 & = P(0.00012) \quad ; \quad P = 8.33 \times 10^4 \text{ lb/hr} \\
 \text{H}_2\text{O:} & F(1.00) + 0 & = P(1 - 0.00012)
 \end{array}$$

$$F = 8.33 \times 10^4 - 10 = 8.33 \times 10^4 \text{ lb/hr}$$

3.37

Assume an unsteady state process although a steady state assumption is also satisfactory (and equivalent).



Steps 1, 2, 3, and 4: Get all the compositions in terms of MgSO₄ and H₂O.

Basis: 1 mol MnSO₄ · 5 H₂O

	Mol	MW	Kg	Mass fr.
MnSO ₄	1	150.94	150.9	0.626
H ₂ O	5	18.02	90.1	0.374
			241.0	1.000

(continued)

Step 5: Basis: 100 kg H_2O

Steps 6 and 7: Unknowns: F and P. Balances $MnSO_4, H_2O$

Steps 8 and 9: Balances are

	Final		Initial	=	In		Out
$MnSO_4$	F (.386)	-	I (0)	=	P (.626)	-	0
H_2O	F (.614)	-	100	=	P (.374)	-	0
	$P = 160 \text{ kg}$				$F = 259.5 \text{ kg}$		

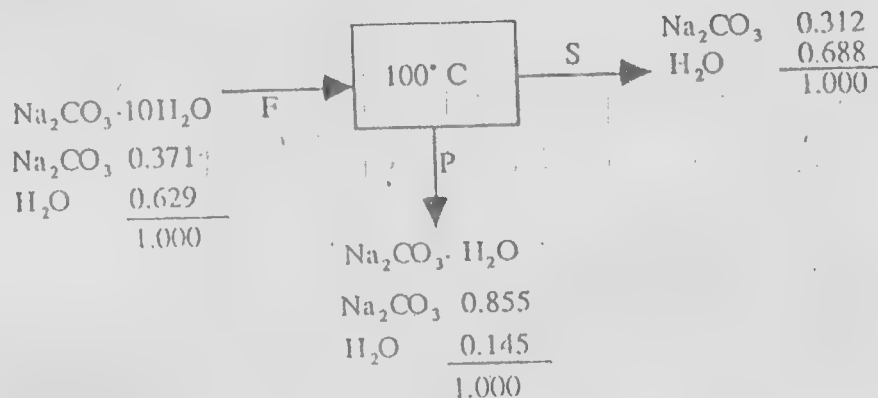
Step 10: Check

$$160 + 100 = 259.5 \quad \text{ok}$$

3.38

This problem can be treated as a steady state flow problem or an unsteady state problem. (The same equations result.)

Steps 1, 2, 3 and 4:



Basis 1 kg mol $\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$

F	Comp.	mol	mol wt	mass	wt fr
	Na_2CO_3	1	106	106	0.371
	H_2O	10	18	180	0.629
	Total			286	1.00

Basis: 1 kg mol $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$

P	Comp.	mol	mol wt	mass	wt fr
	Na_2CO_3	1	106	106	0.855
	H_2O	1	18	18	0.145
	Total			124	1.000

Step 5: Basis: 1 kg $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

Step 6: Unknowns: S, P Let $S_1 - S_2 = \Delta S$ in the balances

Step 7: Balances Na_2CO_3 , H_2O

Steps 8 and 9:

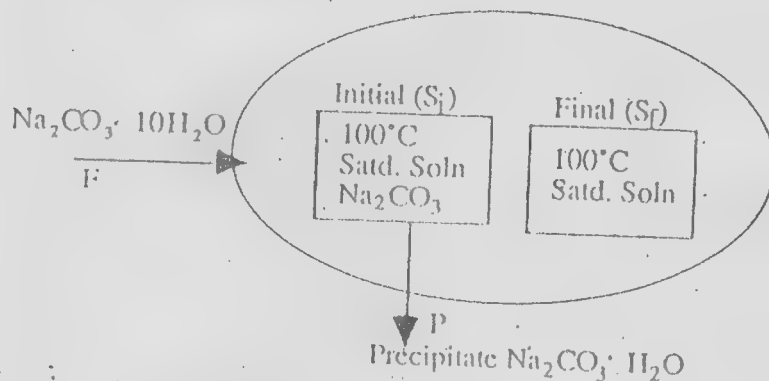
$$\left. \begin{array}{l} \text{Na}_2\text{CO}_3: 0.371(1) = S(0.312) + P(0.855) \\ \text{Total: } 1 = S + P \end{array} \right\} P = 0.109 \text{ kg}$$

Na_2CO_3 in F = 0.371 kg

Na_2CO_3 in P = $0.109(0.855) = 0.093$

$$\frac{0.093}{0.371} = 25\%$$

For an unsteady state analysis



Final - Initial = In - Out

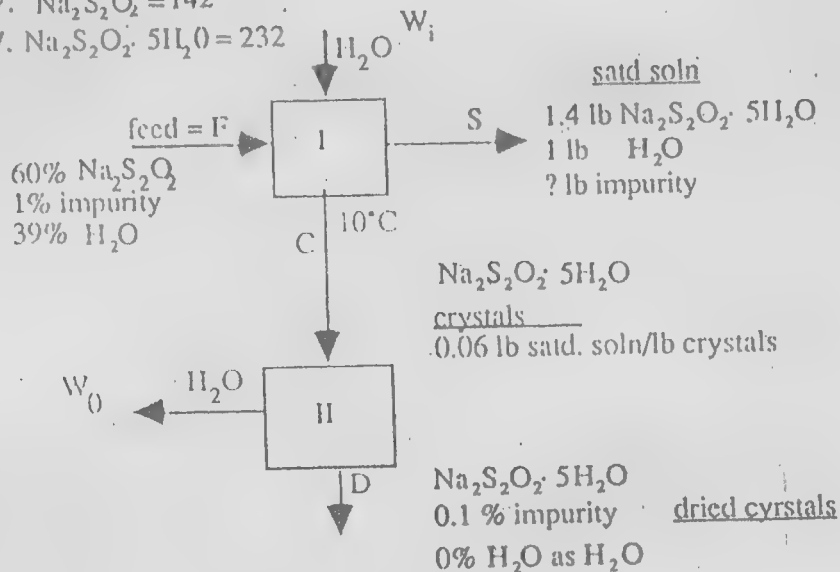
$$\Delta S = S_f - S_i = P - F$$

Let $S_1 - S_2 = \Delta S$ in the balances so that the equations are same for ΔS .

3.39

M.W. $\text{Na}_2\text{S}_2\text{O}_3 = 142$

M.W. $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O} = 232$



Process II Compositions:

a) Stream D Basis: 1 lb mol $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, impurity free

Comp.	lb mol	mol wt	lb	wt fr
$\text{Na}_2\text{S}_2\text{O}_3$	1	142	142	0.612
H_2O	5	18	90	0.388
Total	6		232	1.000

Basis: 100 lb D ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O} = 99.9$ lb)

Comp.			lb
$\text{Na}_2\text{S}_2\text{O}_3$	99(0.612)	=	61.1
H_2O	99(0.388)	=	38.8
impurity			0.1
Total			100.0

Stream C Let $y = \text{lb impurity}/100 \text{ lb free water in saturated solution}$

Basis: 100 lb dry crystals, impurity free

(continued)

Solutions - Chapter - 3

Comp.	lb from dry crystals	+	lb from adhering soln from calculation below	=	Total
$\text{Na}_2\text{S}_2\text{O}_2$	61.2		$(6)\left(\frac{85.7}{240+y}\right)$		$61.2 + 6\left(\frac{85.7}{240+y}\right)$
H_2O	38.8		$(6)\left(\frac{154.3}{240+y}\right)$		$38.8 + \left(\frac{154.3}{240+y}\right)$
impurity	----		$(6)\left(\frac{y}{240+y}\right)$		$\left(\frac{y}{240+y}\right)$
Totals	100.0		6		106

Stream S Basis: 100 lb free water in satd. soln., impurity free

Comp.	lb from salt	lb from free water	Total	wt. fr.	wt. fr. total
$\text{Na}_2\text{S}_2\text{O}_2$	$1.4(61.2) = 85.68$		85.7	0.357	$\frac{85.7}{(240+y)}$
H_2O	$1.4(38.8) = 54.32$	100	154.3	0.643	$\frac{154.3}{(240+y)}$
	140.00	100	240.0	1.000	
impurity =			$\frac{y}{240+y}$		
Total					

Basis: 100 lb F

(Rather than use the impurity balance, use the total balance instead if you want)

Water in, W_i , comes from balances on Unit I.

Total: $100 + W_i = S + C$

$$\left. \begin{array}{l} \text{Na}_2\text{S}_2\text{O}_2 \quad 60 = \left(\frac{85.7}{240+y}\right)S + \frac{61.2 + 6\left(\frac{85.7}{240+y}\right)}{106}C \\ \text{H}_2\text{O} \quad 39 + W_i = \left(\frac{154.3}{240+y}\right)S + \frac{38.8 + 6\left(\frac{154.3}{240+y}\right)}{106}C \end{array} \right\} \begin{array}{l} \text{Unknowns: } W_i, S, C, y \\ \text{Total: 4} \end{array}$$

(continued)

Balances on Unit II needed as well because 4 unknowns exist.

Total: $C = W_0 + D$

$$\left. \begin{array}{l} \text{Na}_2\text{S}_2\text{O}_2 \quad \frac{61.2 + 6\left(\frac{85.7}{240+y}\right)C}{106} = 0.611D \\ \text{H}_2\text{O} \quad \frac{38.8 + 6\left(\frac{154.3}{240+y}\right)C}{106} = W_0 + 0.388D \end{array} \right\} \begin{array}{l} \text{Unknowns: } W_0, D \\ \text{Total: } 2 \end{array}$$

6 equations and 6 unknowns

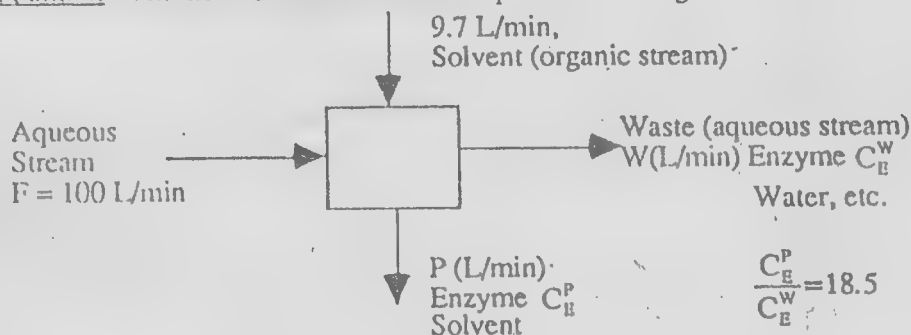
Note that the complex term involving y can be eliminated to solve for D , W_0 , W_i , and S , i.e., in effect making total $\text{Na}_2\text{S}_2\text{O}_2$ and H_2O balances overall the process.

The solution is (a) $W_1 = 23.34 \text{ lb}$ (b) 66.5%

3.40

The extractor is assumed to be a steady state process.

Steps 1, 2, 3, and 4: All the known data have been placed in the figure.



Step 5: Basis: 1 min ($F = 100\text{L}$)

Step 6: Unknowns are P and W and their concentrations.

Steps 7 and 8: We can make enzyme, solvent, and aqueous balances, plus we have

$$C_E^P = 18.5 C_E^W$$

The solvent and aqueous phases are tie components.

(continued)

Balances

$$\begin{array}{c} \text{Enzyme (g)} \\ \text{Phase relation (g/L)} \\ (D = 18.5) \end{array} \quad \begin{array}{c} \text{In} \\ 100\text{L} \left| \frac{10.2\text{ g}}{\text{L}} \right. = \frac{(P\text{ L}) \left| C_E^p \text{ g}}{\text{L}} + \frac{(W\text{ L}) \left| C_E^w \text{ g}}{\text{L}} \right. \end{array}$$

Balances

$$C_E^p = 18.5 C_E^w$$

In

Out

Solvent

$$\frac{9.7\text{L} \left| \rho_s \text{ g}}{\text{L}} = \frac{(P\text{ L}) \left| \rho_r \text{ g}}{\text{L}} \right.$$

Aqueous

$$\frac{100\text{L} \left| \rho_F \text{ g}}{\text{L}} = \frac{W\text{L} \left| \rho_w \text{ g}}{\text{L}} \right.$$

$$P = 9.7\text{L}$$

$$W = 100\text{L}$$

$$1020 = 97 C_E^p + 100 C_E^w = 9.7 (18.5) C_E^w + 100 C_E^w$$

$$C_E^w = 3.65 \frac{\text{g}}{\text{L}}$$

$$C_E^p = 67.53$$

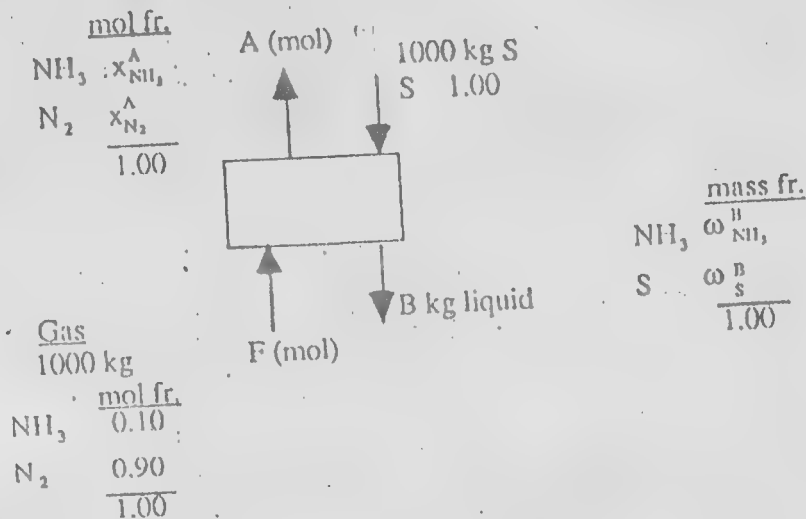
$$\text{Fraction recovery} = \frac{\frac{67.53 \text{ g}}{\text{L}} \left| 9.7 \text{ L}}{\frac{10.2 \text{ g}}{\text{L}} \left| 100 \text{ L}} = 0.64$$

3.41

Assume the process is in the steady state, and no reaction occurs. Solution assume no S is in stream A and no N₂ in stream B.

Steps 1, 2, 3 and 4:

(continued)



Step 5: Basis 1.0 hr

Step 6: The unknowns are A, B, $x_{\text{NH}_3}^A$, $x_{\text{N}_2}^A$, $\omega_{\text{NH}_3}^B$, ω_S^B , a total of 6.

Steps 7 and 8: Three compound balances can be made, N_2 , NH_3 , and S. One relation is given:

$$x_{\text{NH}_3}^A = 2x_{\text{N}_2}^A$$

Two summations exist: $\sum x_i^A = 1$ and $\sum \omega_i^B = 1$

hence, we have an adequate number of balances (unless some are not independent) to solve the problem.

Step 4: (revisited) Find the moles of F by getting the average molecular weight of F.

Basis: 1 g mol F

	mole fr	MW	mass (g)
NH_3	0.10	17.03	1.703
N_2	0.90	28.0	25.200
	1.00		26.903

$$\frac{1000 \text{ kg F}}{26.903 \text{ kg F}} \left| \frac{1 \text{ kg mol F}}{26.903 \text{ kg F}} \right| = 37.171 \text{ kg mol}$$

Steps 7 and 8: (repeated) The balances are.

(continued)

	In	Out
NH ₃ (kg mol):	0.10 (37.171) + 0 (1000) MW _S	$= \frac{\omega_{NH_3}^n(B)}{17.03} + x_{NH_3}^A(A)$
N ₂ (kg mol):	0.90 (37.171) + 0 (1000) MW _S	$= 0(B) + x_{N_2}^A(A)$
S (kg):	0 (1000) + 1000	$= \omega_S^n(B)S + 0(A) MW_A$
	$x_{NH_3}^A + x_{N_2}^A = 1.00$	$\omega_{NH_3}^n + \omega_S^n = 1.00$
		$\omega_{NH_3}^A = 2\omega_{NH_3}^n$

N₂ and S are tie components. Let $x_{NH_3}^A, A = n_{NH_3}^A$, and let $x_{N_2}^A, A = n_{N_2}^A$. Then $n_{NH_3}^A + n_{N_2}^A = A$, and $m_{NH_3}^n + m_S^n = B$

Step 9: A total balance $1000 + 1000 = A + B$ can be used in lieu of one of the above balances. They give

$$m_S^n = 1000 \text{ kg}$$

$$n_{N_2}^A = 0.90(37.171) = 33.45 \text{ kg mol}$$

$$\omega_{NH_3}^n = 0.034$$

$$\omega_S^n = 0.966$$

$$x_{NH_3}^A = 0.0675$$

$$x_{N_2}^A = 0.9325$$

$$A = 35.87 \text{ kg mol / hr or } 965 \text{ kg / hr}$$

$$B = 1035 \text{ kg / hr.}$$

3.42

Steps 1, 2, 3, and 4:

	mass fr.
KI	12.0
I ₂	3.0
H ₂ O	85.0
	100.0

S

	mass fr.
KI	0.088
I ₂	$\omega_{I_2}^P$
H ₂ O	$1 - 0.88 - \omega_{I_2}^P$
	1.0

P

	mass fr.
KI	2.5
I ₂	0.675
H ₂ O	96.875
	100.0

W

Step 5: Basis : S = 100 kg

Steps 6 and 7: Unknowns: W, P, $\omega_{I_2}^P$

Balances: KI, I₂, H₂O

Steps 8 and 9:

Balances:

$$\begin{aligned}
 \text{KI:} \quad & 12 + 0.025 W = P (0.088) & (a) \\
 \text{I}_2: \quad & 3 + 0.00675 W = m_{I_2}^P = P \omega_{I_2}^P & (b) \\
 \text{H}_2\text{O:} \quad & 85 + 0.96875 W = P (1 - \omega_{I_2}^P - 0.088) & (c) \\
 \text{Total:} \quad & 100 + W = P & (d)
 \end{aligned}$$

Solve (a) and (d):

$$W = 50.79 \text{ kg}$$

$$R = S/W = \frac{100}{50.79} = 1.97$$

$$P = 150.79 \text{ kg}$$

$$S (0.12) + 0.25 W = P (\omega_{KI}) \quad \text{so} \quad WR (0.12) + 0.25 W = P (\omega_{KI})$$

(continued)

$$W(0.12R + 0.025) = P\omega_{KI}$$

b) Replace 0.088 in equation (a) by ω_{KI}^P . Then we get 4 unknowns and 3 equations. Solve for $\omega_{KI}^P/\omega_{I_2}^P$ in terms of $R = \frac{S}{W}$

$$S(0.03) + 0.00675W = P\omega_{I_2} \text{ so, } WR(0.03) + 0.00625W = P\omega_{I_2}^P$$

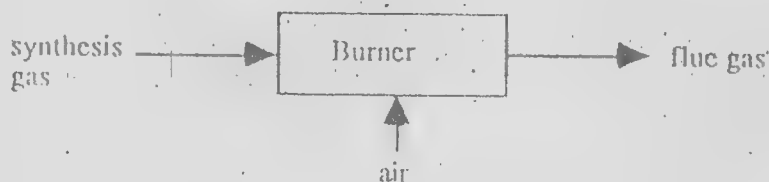
$$W(0.03R + 0.00625) = P\omega_{I_2}^P$$

$$\frac{(0.12R + 0.025)}{(0.03R + 0.00625)} = \frac{\omega_{KI}}{\omega_{I_2}}$$

The above relationship shows that if we start with a given strong solution ($\omega_{KI,S}$ and $\omega_{I_2,S}$ fixed) and a given weak solution ($\omega_{KI,W}$ and $\omega_{I_2,W}$ fixed), then specifying $\omega_{KI,P}$ totally determines the unique value of $\omega_{I_2,P}$ permitted. This demonstrates that one cannot independently vary both $\omega_{KI,P}$ and $\omega_{I_2,P}$.

3.43

Basis: 100 kg mol



One composition is unknown, the flue gas. After selection of a basis, the air flow is known. Hence, this problem can be solved by direct addition and subtraction

Unknowns: $(CO_2, H_2O, N_2, O_2) = 4$

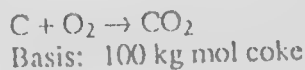
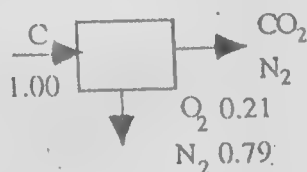
Balances: $(C, H, O, N) = 4$

Comp.	%=mol	Reaction	reqd. O_2	CO_2	H_2O	N_2	O_2
CO_2	6.4	-----	-----	6.4			
O_2	0.2	-----	-(0.2)				
CO	40.0	$CO + 1/2 O_2 \rightarrow CO_2$	20.0	40.0			
H_2	50.8	$H_2 + 1/2 O_2 \rightarrow H_2O$	25.4		50.8		
N_2	2.6	-----				2.6	
	XS O_2 : $(0.40)(45.2) =$		18.08				18.08
	Total O_2 in		63.28				
	N_2 in with O_2 $(63.28)(79/21) =$					238.05	
	Totals			46.4	50.8	240.65	18.1

(continued)

Comp.	mol	%
CO ₂	46.4	13.0
H ₂ O	50.8	14.3
N ₂	240.65	67.6
O ₂	<u>18.1</u>	<u>5.1</u>
Totals	356.0	100.0

3.44



a.
$$\frac{100 \text{ kg mol C}}{1 \text{ mol C}} \left| \frac{1 \text{ mol O}_2}{1 \text{ mol C}} \right| \frac{79 \text{ mol N}_2}{21 \text{ mol O}_2} = 376 \text{ kg mol N}_2$$

b.

Component	kg mol	Vol%
N ₂	376	79
CO ₂	<u>100</u>	21
Total	476	<u>100</u>

Comp.	kg mol	Vol%
CO ₂	100	14
O ₂	50	7
N ₂	<u>564</u>	<u>79</u>
Total	714	<u>100</u>

With 50% xs air, xs O₂ is 50 mol
$$\frac{150}{0.21} \left| \frac{0.79}{0.21} \right| = 564$$

c. Same 150 mol O₂ enter and 564 mol N₂ exit but O₂ is different

	<u>In</u>		<u>mol CO₂ used</u>		<u>Used CO</u>
Oxygen balance:	150	-	90	-	5 = 55 kg mol O ₂ lb fg

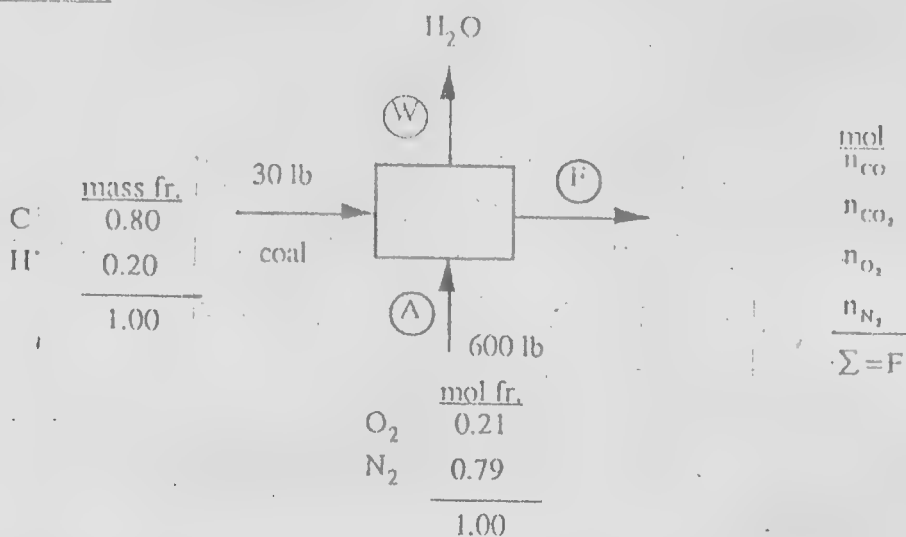
(continued)

Solutions - Chapter - 3

Component	kg mol	Vol%
CO ₂	90	12.51
CO	10	1.39
O ₂	55	7.65
N ₂	564	78.45
Total	719	100.00

3.45

Steps 1, 2, 3, and 4:



Steps 5 and 6: With a basis of 30 lb coal, only n_{N_2} , n_{O_2} , n_{CO_2} , n_{CO} , F and W are unknown.
Total 6

Step 7: Can make C, H, O, N balances.

plus $\frac{n_{\text{CO}_2}}{n_{\text{CO}}} = \frac{3}{2}$ and $\Sigma n_i = F$

Do calculations in moles but you don't need to make all of the balances

Comp.	lb	mol wt	lb mol	Rxn	lb mol reqd O ₂
C	24	12	2	C+O ₂ →CO ₂	2.0
H ₂	6	2	3	H ₂ +1/2O ₂ →H ₂ O	1.5
	30				3.5
3.5 lb mol O ₂ 1.00 lb mole air = 16.67 lb mol air reqd.					
0.21 lb mol O ₂					

(continued)

$$\frac{600 \text{ lb air}}{29 \text{ lb air}} \times \frac{1 \text{ lb mol air}}{29 \text{ lb air}} = 20.69$$

or

$$\left(\frac{600}{29}\right)(.21) = 4.35 \text{ lb mol O}_2$$

$$\% \text{ excess air} = \frac{20.69 - 16.67}{16.67}(100)$$

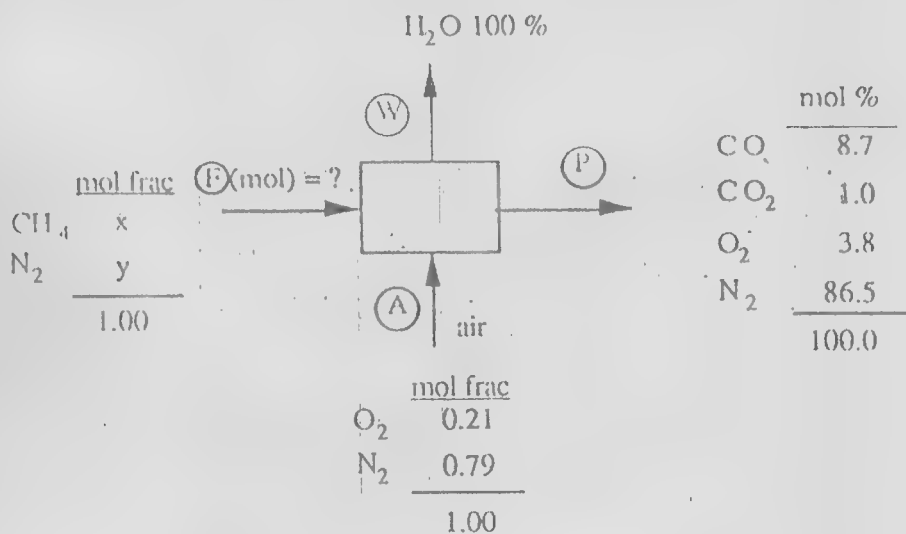
$$= 24.1\%$$

$$\text{or } \frac{4.35 - 3.5}{3.5}(100)$$

$$= 24.3\%$$

3.46

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 mol P

Step 6: Unknowns: x, y, A, W, F Total 5

Step 7: Balances: C, H, N, O

a) If x and y are moles, not mole fractions, add: $x + y = F$ b) If $x + y = 1.00$, x, y are mole fr.

Steps 8 and 9:

C balance: $x = 8.7 + 1.0 = 9.7$

N₂ balance: $y + .79A = 86.5$

H₂ balance: $2x = W = 2(9.7) = 19.4$

O₂ balance: $0.21A = 1/2 W + 8.7 + 1/2 (1.0) + 3.8$

(XOVTVVDEδ)

Solutions - Chapter - 3

Using x, y as mol, the equations are slightly easier to solve.

Use O₂ bal: $A = \frac{9.7 + 8.7 + 0.5 + 3.8}{0.21} = 108$

Use N₂ bal: $y = 1.10$



$(9.7)(2) = 19.4 \text{ mol}$

total O₂ in: $(0.21)(108) = 22.7$

excess O₂ = $22.7 - 19.4 = 3.3 \text{ mol}$

% xs air = % xs O₂ = $\frac{3.3}{19.4}(100)$

(a) = 17%

(b) Percentage of CH₄, N₂: $\text{CH}_4 = \frac{9.7}{9.7 + 1.1}(100) = \text{89.8\%}$ $\text{N}_2 = \frac{1.1}{9.7 + 1.1}(100) = \text{10.2\%}$

Alternate Solution:

	%	mol C	O ₂
CO ₂	8.7	8.7	8.7
CO	1.0	1.0	0.5
O ₂	3.8		3.8
N ₂	86.5		
	100.0	9.7	13.0

mole CH₄ in = 9.7

mole O₂ in = 13.0 + O₂ in H₂O.

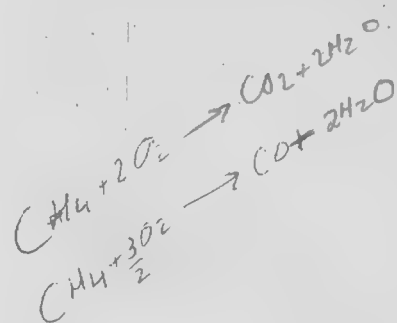
= 13.0 + 9.7 = 22.7

mole N₂ in = 86.5 - 22.7 (0.79/0.21) = 1.1

9.7 mol C requires 19.4 mol O₂

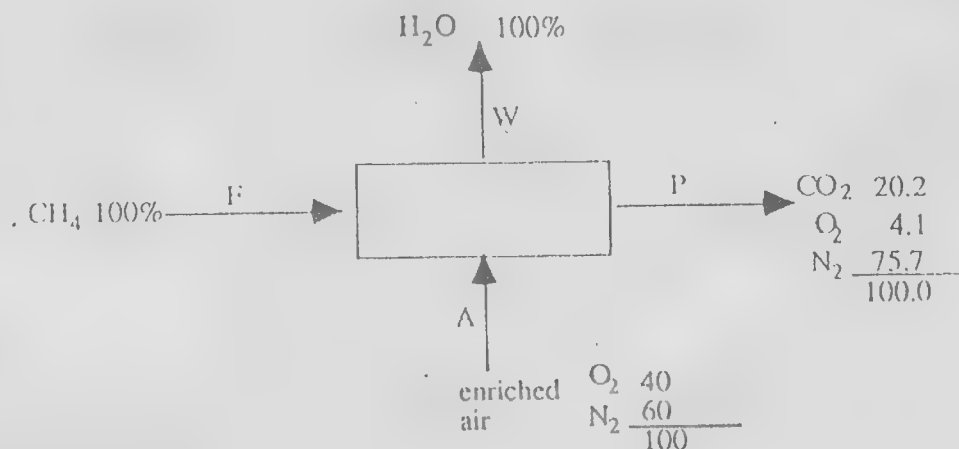
excess O₂ = 3.8 - 1/2 (1.0) = 3.3

↑ O₂ that make CO → CO₂



3.47

Steps 1, 2, 3 and 4:



Step 5: Basis 100 mol P

Step 6: Unknowns: F, A, W (all compositions known)

Step 7: Balances: C, H, O, N (1 extra balance)

Steps 8 and 9:

C balance: $20.2 = F$

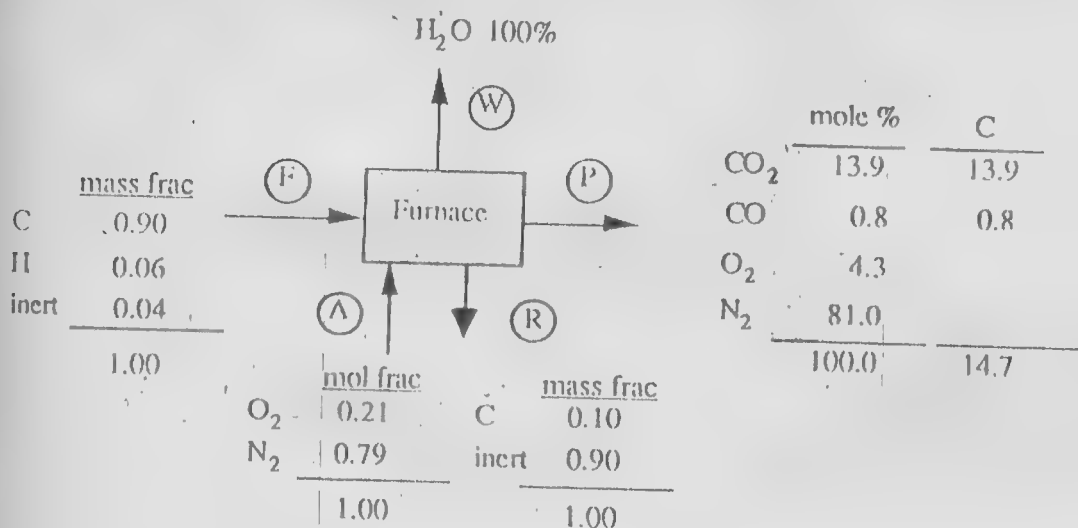
N_2 balance: $75.7 = 0.6A$, $A = 126.2$

H_2 balance: $2F = W$, $W = 40.4$

O_2 balance: $0.4A = 1/2 W + 20.2 + 4.1$, $50.5 \neq 20.2 + 20.2 + 4.1 = 44.5$

Analysis is not correct

3.48



Basis: 100 kg mol P

Unknowns: F, R, A, W

④

Probably ok but check for redundancy

Balances: C, H, O, inert, N₂

⑤

Balances (in moles):

$$\text{C: } \frac{F(0.90)}{12} = P(0.139 + 0.008) + \frac{R(0.10)}{12} + W(0)$$

$$\text{H: } \frac{F(0.06)}{1.005} = P(0) + R(0) + W(2)$$

$$\text{N}_2: A(0.79) = P(0.81) + R(0) + W(0)$$

$$\text{O}_2: A(0.21) = P(0.139 + \frac{0.008}{2} + 0.043) + \frac{W}{2}$$

$$\text{Inert (mass): } F(0.04) = R(0.90)$$

$$\text{From N}_2, A = \frac{100(0.81)}{0.79} = 102.53 \text{ kg mol}$$

$$\text{From O}_2, W = 5.863 \text{ kg mol}$$

(continued)

Solutions - Chapter - 3

From H, $F = 196.98 \text{ kg}$

From inert, $R = 8.7548 \text{ kg}$

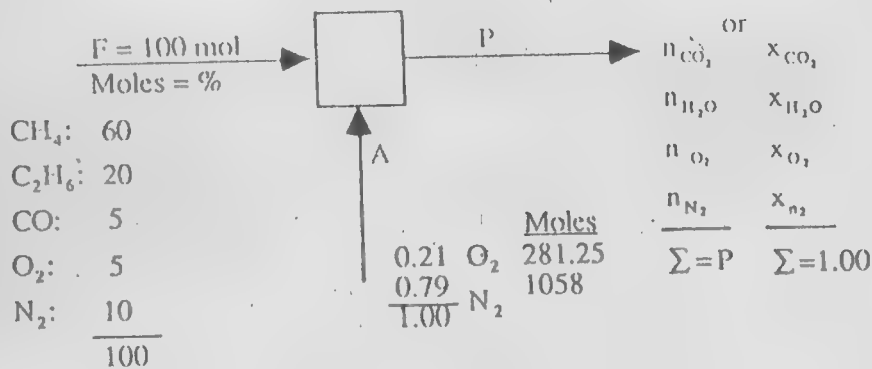
Check via C: $196.98 (0.90) / 12 = 100 (0.147) + (8.7548 (0.10) / 12)$ ok

Required O_2 : $14.7 + (5.863/2) = 17.63 \text{ kg mol}$ Total $O_{2in} = 102.53 (0.21) = 21.53$

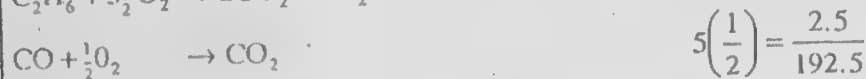
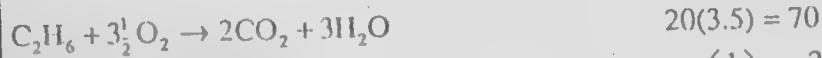
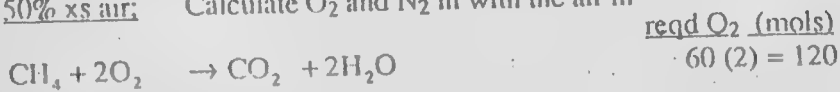
Excess $(21.53 - 17.63) / 17.63 = 0.221 \text{ or } 22\%$

3.49

Basis: 100 mol F



50% xs air: Calculate O₂ and N₂ in with the air in



Less O₂ in gas 5.00

Net required O₂ 187.5

xs O₂: 187.5 (.5) = 93.75

Total 281.25

N₂ in with O₂ $\frac{281.25}{0.21} \times 0.79 = 1058$

(continued)

Solutions - Chapter - 3

Material balances (elemental):

	in (F)	+	in (A)	=	out (P)
C:	$60 + 2(20) + 5$	+	0	=	n_{CO_2}
H:	$60(4) + 20(6)$	+	0	=	$n_{H_2O}(2)$
O as O ₂ :	$\frac{5}{2} + 5$	+	281.25	=	$n_{CO_2} + \frac{n_{H_2O}}{2} + n_{O_2}$
N as N ₂ :	10	+	1058	=	n_{N_2}

$$n_{O_2} = 288.75 - 105 - \frac{180}{2} = 93.75$$

moles

composition of stack in % moles

$$n_{CO_2} = 105$$

$$n_{H_2O} = 180$$

$$n_{N_2} = 1068$$

$$n_{O_2} = 93.75$$

7.26

12.44

73.82

6.48

$$\text{Total moles out} = 1446.75$$

$$100.00$$

3.50

<u>mole fr</u>				<u>mol fr</u>	
CH ₄	0.70	Fuel F mol Flare Air A mol Flue gas P mol	CO ₂	0.0773	
C ₃ H ₈	0.05		H ₂ O	0.1235	
CO	0.15		O ₂	x _{O₂}	
O ₂	0.05		N ₂	x _{N₂}	
N ₂	0.05				
	1.00			1.00	

	<u>mol frs</u>
O ₂	0.21
N ₂	0.79
	1.00

Unknowns A, F, P, x_{O_2} , x_{N_2} , Pick F = 100 as basis

(4)

(continued)

(5)

Balances: C, H, O, N (are redundant?) plus
 $0.0773 + 0.1235 + x_{O_2} + x_{N_2} = 1$

Balances:

$$C: 100(0.70) + 100(0.05)(3) + 100(0.15) = P(0.0773)$$

$$N_2: 100(0.05) + 0.79A = P x_{N_2}$$

$$H_2: 100(0.70)(2) + 100(0.05)4 = P(0.1235) \text{ (redundant with C)}$$

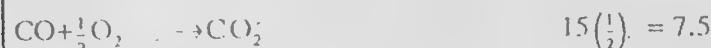
$$O_2: 100(0.15)\frac{1}{2} + 100(0.05) + A(0.21) = P(0.0773) + \frac{0.1235}{2} + x_{O_2}$$

$$\Sigma X_i = 0.7992 = x_{O_2} + x_{N_2}$$

$$\text{Solve C (or } H_2 \text{) balance for } P; \quad P = 1294$$

Solve N_2 , O_2 and $\Sigma X_i = 1$ simultaneously for A , x_{O_2} , x_{N_2}

$$A = 1203 \text{ moles} \quad x_{O_2} = 0.0648 \text{ and } x_{N_2} = 0.7344 \text{ (not needed)}$$

Calculation of the required O_2 Required O_2 

$$O_2 \text{ present in F:} \quad \frac{-5.0}{167.5 \text{ reqd}}$$

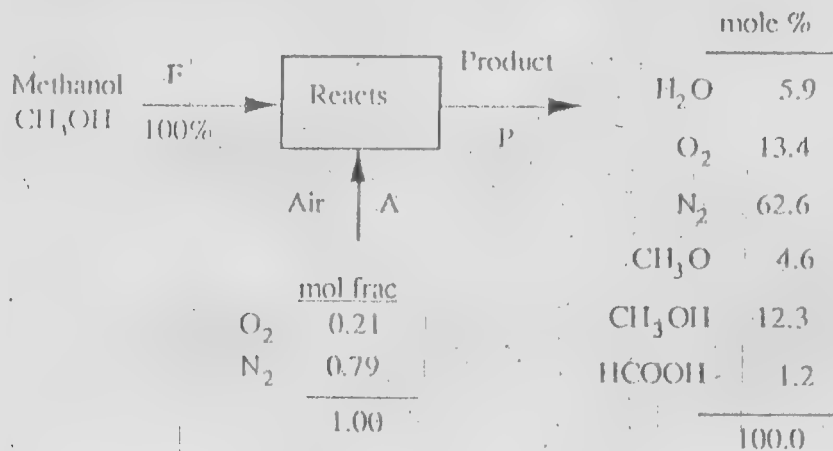
$$A(0.21) = 252.54 \text{ } O_2 \text{ in } \cancel{X}$$

$$\text{less } \frac{167.5 \text{ reqd } O_2}{85.04 \text{ xs } O_2}$$

$$\frac{85.04}{167.5} (100) = \boxed{51\%}$$

3.51

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 mol P

Step 6: Unknown: F, A (2)

Step 7: Balances: N, H, O, C (4)

More balances than unknowns. Are they independent?

Steps 8 and 9:

Check by solving C, N (tie elements)

C: $F(1) = 4.6 + 12.3 + 1.2 = 18.1$

$F = 18.1 \text{ mol}$

N₂: $A(0.79) = 62.6$

$A = 79.24 \text{ mol}$

Check O: (2) $(79.24)(.21) + 18.1 \stackrel{?}{=} 13.4(2) + 5.9 + 4.6 + 12.3 + 1.2(2)$

$51.38 \quad \stackrel{?}{=} 52.0$

close but not exactly the same, more oxygen out than in

Check H: $4(18.1) \stackrel{?}{=} 5.9(2) + 4.6(3) + 12.3(4) + 1.2(2)$

$72.40 \quad \stackrel{?}{=} 77.20$

not the same; more hydrogen out than in

(continued)

Solutions - Chapter - 3

If N_2 and C balances are ok:
What comes in must be
possibly

$$\begin{array}{rcl} 77.20 - 72.40 & = & 4.80 \text{ H or } 2.40 \text{ H}_2 (?) \\ 52.0 - 51.28 & = & 0.620 \end{array}$$

But more likely a carbon compound enters, or leaves. Assume N_2 and H balances are ok.

$$N_2: \quad A \quad = 79.24$$

$$H: \quad F(4) \quad = 77.20, \quad F = 19.30 \text{ mol}$$

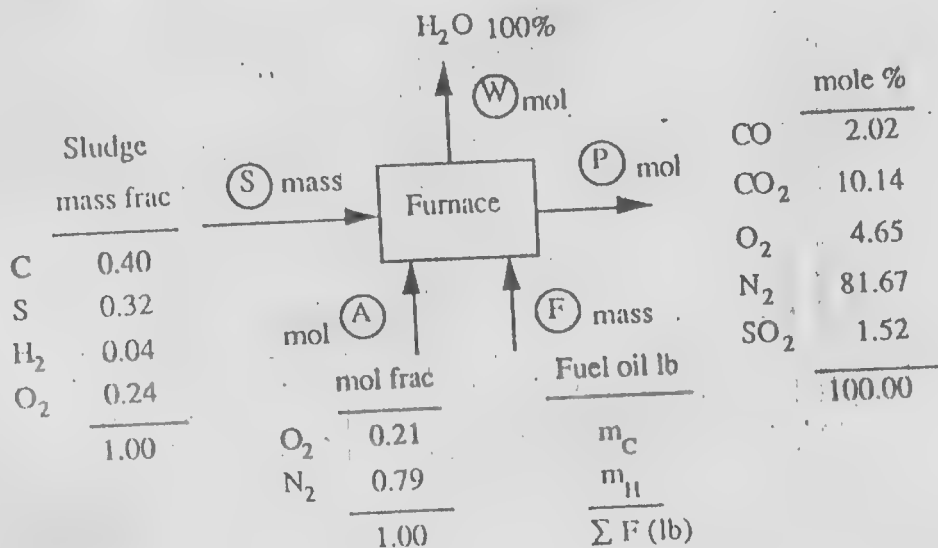
Check C balance

$$19.30 \text{ in} \quad \text{vs} \quad 18.1 \text{ out}$$

possibly some organic is missed in product?

Other possibilities exist as well such as the analysis values are wrong.

3.52



Basis: 100 mol P

Unknowns: S, W, F, A, m_C

⑤ Balances: S, C, H, O, N

⑤

Balances (moles)

$$S: \quad \frac{0.32S}{32} \quad = \quad 1.52$$

$$S = 152 \text{ lb}$$

$$N_2: \quad A(79) \quad = \quad 81.67$$

$$A = 103.38 \text{ lb mol (2998.01 lb)}$$

(continued)

Solutions - Chapter - 3

$$C: \frac{S(0.40)}{12} + \frac{m_C}{12} = 10.14 + 2.02 \quad m_C = 85.12 \text{ lb}$$

$$O_2: \frac{0.24(152)}{32} + \Lambda(0.21) = \frac{W}{2} + 1.52 + 10.14 + 4.65 + \frac{2.02}{2}$$

$$W = 11.04 \text{ lb mol (198.71 lb)}$$

$$H_2: \frac{0.04(152)}{2.03} + \frac{m_H}{2.03} = W \quad m_H = 16.32 \text{ lb}$$

Check via a total mass balance

$$152 + 16.32 + 85.12 + 2998.01 \quad ? \quad 198.71 + 3035.56$$

$$3251.45 \quad ? \quad 3234.27 \quad \text{close enough}$$

	lb	mass fr
C	85.12	0.84
H	16.32	0.16
	101.44	1.05

$$\frac{S}{F} = \frac{152 \text{ lb}}{101.44 \text{ lb}} = 1.50$$

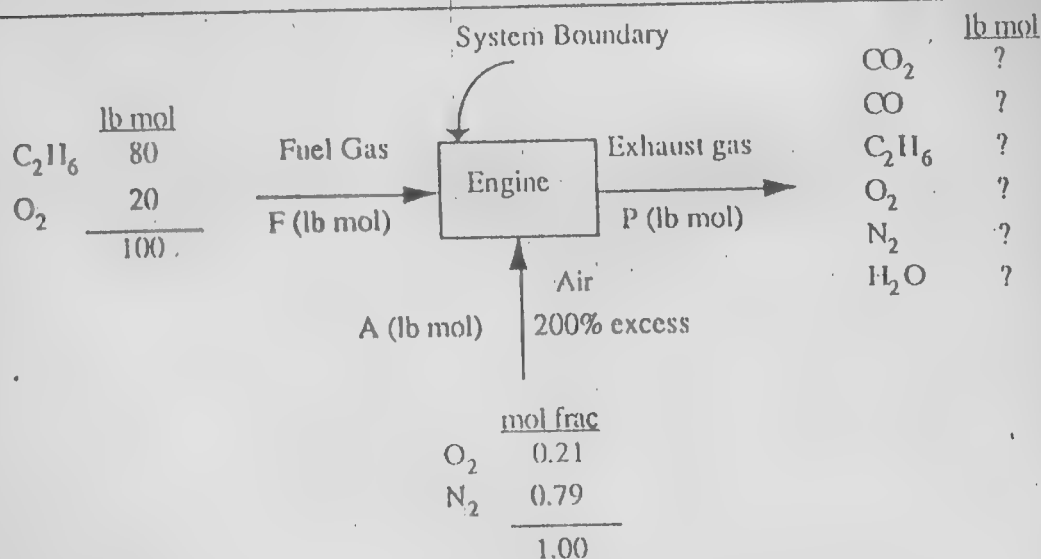
← (B)

3.53

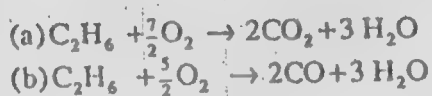
Assume the problem is in the steady state. We know the composition of the air and fuel gas; if a weight of fuel gas is chosen as the basis, the weight of air can easily be calculated. However, it is wasted effort to convert to a weight basis for this type of problem because all the compositions are expressed in moles or mole percent for gases. We will first make element balances to solve this problem, and then employ the reaction stoichiometry together with material balances to obtain the composition of the stack gas. The generation and consumption terms in the material balances can be evaluated from the stoichiometric equations listed below.

Steps, 1, 2, 3 and 4: All the known information has been placed in the Figure below.

(continued)



The reactions involved are:



Step 5: Let the basis be 100 lb mol of fuel

Step 4 (repeated) The next activity is to calculate the amount of entering air, and O₂ and N₂

The total O₂ entering is 3.00 times the required O₂ (100% required plus 200% excess).
Let us calculate the required oxygen:

O₂ (for complete combustion):

$$\frac{80 \text{ lb mol } C_2H_6}{1 \text{ lb mol } C_2H_6} \left| \frac{3.5 \text{ lb mol } O_2}{1 \text{ lb mol } C_2H_6} \right| = 280 \text{ lb mol } O_2$$

Required O₂:

$$280 - 20 = 260 \text{ lb mol } O_2$$

(Note: The oxygen used to completely burn the fuel is reduced by the oxygen already present in the fuel to obtain the oxygen required in the entering air.)

Next we calculate the input of O₂ and N₂ to the system:

O₂ entering with air:

$$3(260 \text{ lb mol } O_2) = 780 \text{ lb mol } O_2$$

(continued)

Solutions - Chapter, 3

$$\text{N}_2 \text{ entering with air: } \frac{780 \text{ lb mol O}_2}{0.21 \text{ O}_2} \left| \frac{0.79 \text{ N}_2}{0.21 \text{ O}_2} \right. = 2934 \text{ lb mol N}_2$$

Step 6: Seven unknowns can be identified in the figure, the moles of the six compounds in P and the value of P.

Steps 4, 7 and 8: Four element balances can be made and $P = \sum n_i^P$ (where n_i^P represents the moles of compound i in P). What other information or equations exist? From the problem statement $0.80(80) = 64 \text{ lb mol C}_2\text{H}_6$ burns to CO_2 yielding $2(0.80)80 = 128 \text{ lb mol CO}_2$ in P. Similarly $2(0.10)(80) = 16 \text{ lb mol CO}_2$ is in P, and $(0.10)(80) = 8 \text{ lb mol C}_2\text{H}_6$ exists unburned.

These calculations leave us with four unknowns; P , $n_{\text{O}_2}^P$, $n_{\text{N}_2}^P$, and $n_{\text{H}_2\text{O}}^P$ to be solved for by 5 equations. A unique solution exists if only 4 of the 5 equations are independent. Rather than check the rank of the coefficient matrix, let us assume that the 4 elements balances are independent, and use $P = \sum n_i^P$ as a check. If it checks, then one of the 5 equations is redundant. The balances are all in lb mol and the accumulation is zero.

Balance	In E	In A	Out in P
C:	$2(80) +$	$0 =$	$128 + 16 + 2(8)$
N ₂ :	$0 +$	$2934 =$	$n_{\text{N}_2}^P$
H:	$6(80) +$	$0 =$	$6(8) + 2n_{\text{H}_2\text{O}}^P$
O ₂ :	$20 +$	$780 =$	$128 + (1/2)16 + (1/2)n_{\text{H}_2\text{O}}^P + n_{\text{O}_2}^P$

From these equations we get in summary

Component	lb mol			Percent in exhaust gas
	Fuel	Air	Exhaust gas	
C ₂ H ₆	80	---	8	0.2
O ₂	20	780	556	14.41
N ₂	---	2934	2934	76.05
CO ₂	---	---	128	3.32
CO	---	---	16	0.41
H ₂ O	---	---	216	5.60
Total	100	3714	3858	100.00

On a dry basis we would have (the water is omitted in the exhaust gas):

Component	lb mol	Percent
C ₂ H ₆	8	0.22
O ₂	556	15.27
N ₂	2934	80.56
CO ₂	128	3.51
CO	16	0.44
Total	3642	100.00

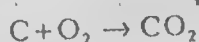
3.54

Solution

$$\% \text{ excess air} = \left(\frac{k}{\% \text{CO}_2} - 1 \right)$$

a) coke

$$100 \left(\frac{20.5}{12.1} - 1 \right) = 69.4\%$$



b) NG

$$100 \left(\frac{12.5}{12.1} - 1 \right) = 3.3\%$$



a) Basis: 100 mol dry flue gas out

$$\frac{12.1 \text{ mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} \right| \frac{1 \text{ mol O}_2}{1 \text{ mol CH}_4} = 12.1 \text{ mol O}_2 \text{ reqd.}$$

If the excess O₂ is 69.4%, 12.1 (0.694) = $\frac{8.4}{20.5}$ $\frac{\text{mol O}_2 \text{ xs}}{\text{Total O}_2 \text{ in}}$

N₂ in = 20.5 $\left(\frac{79}{21} \right)$ = N₂ out 77.1 mol N₂

CO₂ out = 12.1 mol CO₂

O₂ out = 20.5 - 12.1 = 8.4 mol O₂

97.6 < 100 but close

b) Basis: 100 mol dry flue gas out

$$\frac{12.1 \text{ mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{1 \text{ mol CH}_4}{1 \text{ mol CO}_2} \right| \frac{2 \text{ mol O}_2}{1 \text{ mol CH}_4} = 24.1 \text{ mol O}_2 \text{ reqd.}$$

If the excess O₂ is 3.3%, 24.1 (0.033) = $\frac{0.8}{24.9}$ $\frac{\text{mol O}_2 \text{ xs}}{\text{mol O}_2 \text{ total}}$

N₂ in = 24.9 $\left(\frac{79}{21} \right)$ = 93.7 = N₂ out 93.7 mol N₂

CO₂ out = 12.1 mol CO₂

O₂ out = 24.9 - 24.1 = 0.8 mol O₂

106.6 > 100 but close

(continued)

% xs air

$$F \left(\frac{\% \text{O}_2}{21 - \% \text{O}_2} \right)$$

a) coke $100 \left(\frac{8.6}{21 - 8.6} \right) = \boxed{69.4\%}$

b) NG $90 \left(\frac{0.8}{21 - 0.8} \right) = \boxed{3.5\%}$

3.55

Steps 1, 2, 3, and 4: To solve this problem you must recall that CaCO_3 reacts with H_2SO_4 to form CaSO_4 and that CaCO_3 when heated yields CO_2 and CaO whereas when CaSO_4 is heated at the same time it does not decompose. Although the problem seems to be underspecified, when you draw a diagram of the process and place the known data on it, the situation becomes clearer. Assume the process is a steady state one with reaction. Then the element balances are just *in* = *out*.

Note that we have designated the composition of P in terms of the mass of each component, m_i^P , rather than the mass fraction ω_i^P , because this choice makes the element balances linear.

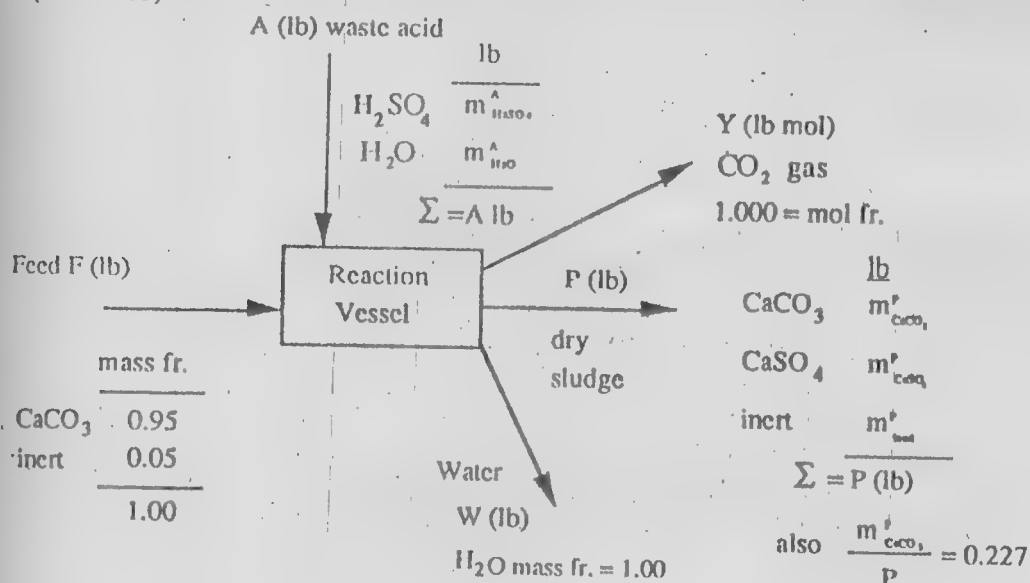
The CO_2 liberated from the sludge is equivalent to

$$\frac{1 \text{ lb } \text{CO}_2}{10 \text{ lb } P} \left| \frac{1 \text{ lb mol } \text{CO}_2}{44 \text{ lb } \text{CO}_2} \right| \left| \frac{1 \text{ lb mol } \text{CaCO}_3}{1 \text{ lb mol } \text{CO}_2} \right| \left| \frac{100.09 \text{ lb } \text{CaCO}_3}{1 \text{ lb mol } \text{CaCO}_3} \right|$$

$$= 0.227 \text{ lb } \text{CaCO}_3 / \text{lb } P$$

We will let the compositions be designated in mass rather than mass fraction to avoid products such as ω^P .

(continued)



Step 5:

Basis: $F = 100 \text{ lb}$

Step 6: The variables whose values are unknown are Λ , $m_{H_2SO_4}^\Lambda$, $m_{H_2O}^\Lambda$, $m_{CaCO_3}^P$, $m_{CaSO_4}^P$, m_{inert}^P , P , W , and Y , a total of 9.

Step 7: The element balances that can be made are Ca, C, O, S, H, inert (6 total) and we know $\Sigma m_i^\Lambda = \Lambda$, $\Sigma m_i^P = P$, and $(m_{CaCO_3}^P / P) = 0.227$ for a total of 9. If the equations are independent, we can find a unique solution.

Steps 8 and 9: The equations (*in* = *out*) are (except for the inert balance which is in lb) in moles

$$\text{Ca: } \frac{95 \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaCO}_3}$$

$$= \frac{m_{CaCO_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaCO}_3}$$

$$+ \frac{m_{CaSO_4}^P \text{ lb CaSO}_4}{136.15 \text{ lb CaSO}_4} \left| \frac{1 \text{ lb mol CaSO}_4}{1 \text{ lb mol CaSO}_4} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaSO}_4}$$

$$\text{C: } \frac{0.95 \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CaCO}_3} = \frac{Y \text{ lb mol CO}_2}{1 \text{ lb mol CO}_2} \left| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CO}_2} \right|$$

$$+ \frac{m_{CaCO_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CaCO}_3}$$

(continued)

$$\text{S: } \frac{m_{H_2SO_4}^\Lambda \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{1 \text{ lb mol H}_2\text{SO}_4} \right| \frac{1 \text{ lb mol S}}{1 \text{ lb mol H}_2\text{SO}_4}$$

$$= \frac{m_{CaSO_4}^P \text{ lb CaSO}_4}{136.25 \text{ lb CaSO}_4} \left| \frac{1 \text{ lb mol CaSO}_4}{1 \text{ lb mol CaSO}_4} \right| \frac{1 \text{ lb mol S}}{1 \text{ lb mol CaSO}_4}$$

$$\text{H}_2: \frac{m_{H_2SO_4}^\Lambda \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{1 \text{ lb mol H}_2\text{SO}_4} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{SO}_4}$$

$$+ \frac{m_{H_2O}^\Lambda \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{O}}$$

$$= \frac{W \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{O}}$$

$$\begin{aligned}
 \text{O: } & \frac{95 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{3 \text{ lb mol O}}{1 \text{ lb mol CaCO}_3} \\
 + & \frac{m_{\text{H}_2\text{SO}_4}^A \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{1 \text{ lb mol H}_2\text{SO}_4} \right| \frac{4 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{SO}_4} \\
 + & \frac{m_{\text{H}_2\text{O}}^A \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \frac{1 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{O}} \\
 = & \frac{Y \text{ lb mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{2 \text{ lb mol O}}{1 \text{ mol CO}_2} \right| \\
 + & \frac{m_{\text{CaCO}_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \frac{3 \text{ lb mol O}}{1 \text{ lb mol CaCO}_3} \\
 + & \frac{m_{\text{CaSO}_4}^P \text{ lb CaSO}_4}{136.15 \text{ CaCO}_4} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaSO}_4} \right| \frac{4 \text{ lb mol O}}{1 \text{ lb mol CaSO}_4} \\
 + & \frac{W \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \frac{1 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{O}}
 \end{aligned}$$

$$\text{Inert: } 5 \text{ lb inert} = m_{\text{inert}}^P \text{ lb inert}$$

The solution of these equations using a computer code would give all of the values of the unknown quantities. However, a review of the set of equations, after having gone into great detail about each equation, indicates that only 4 of the equations have to be solved to get the desired answer, namely the Ca balance, the $\Sigma m_i^P = P$, and the inert balance plus $m_{\text{CaCO}_3}^P = 0.227$;

(continued).

$$\Sigma m_i^P = P: \quad m_{\text{CaCO}_3}^P + m_{\text{CaSO}_4}^P + 5 = P = m_{\text{CaCO}_3}^P / 0.227$$

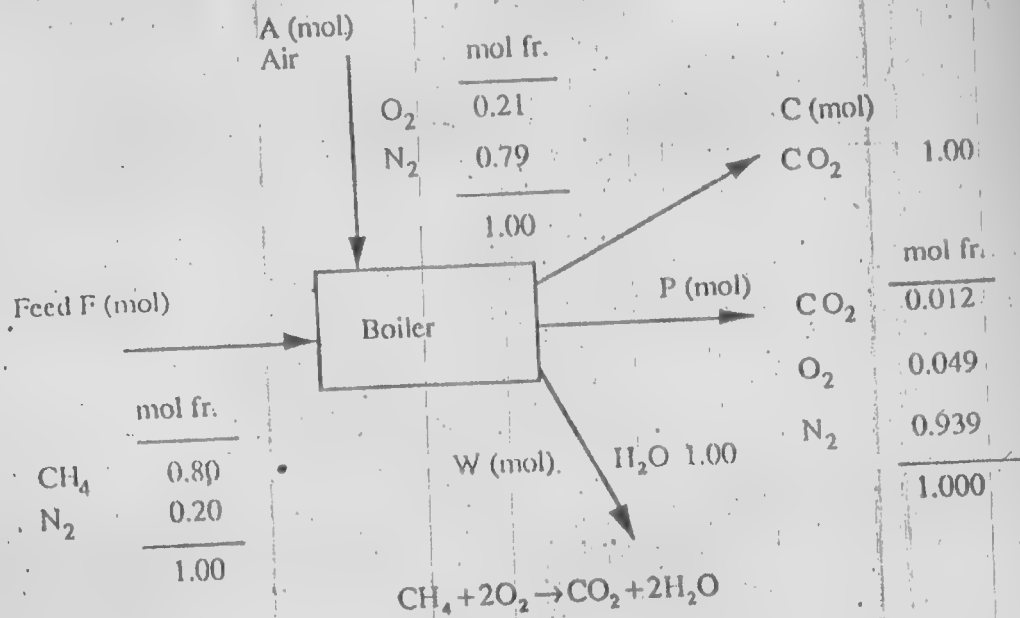
$$\text{Ca: } \quad 0.949 = 0.010 m_{\text{CaCO}_3}^P + 0.00734 m_{\text{CaSO}_4}^P$$

$$m_{\text{CaCO}_3}^P = 28.55 \text{ lb} \text{ and } 100 \frac{28.55}{95} = 30\% \text{ unreacted.}$$

What would happen if the CaSO_4 in the dried sludge were not anhydrous CaSO_4 but more realistically gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$? The water of hydration would be driven off along with the CO_2 on heating the sludge. But if the water vapor were not inadvertently added to the CO_2 in the analysis, the problem would remain the same -- the water driven off could be included in W and later on the dry sludge analysis adjusted to include the of hydration water.

Solutions - Chapter - 3

Assume a steady state process



Steps 1,2,3 and 4:

All known data are on the figure

Step 5:

Basis:

F = 100 mol

Step 6:

Unknown are

W, P, A, C

Step 7, 8:

Balances are

C, H, O, N so the problem has a solution if 4 independent equations exist among the mole balances

(continued)

Steps 8 and 9:

Balances

	In		Out
C:	$100(0.80)$	=	$P(0.012) + C$
H:	$100(0.80)4$	=	$W(2) \quad W = 160$
N ₂ :	$100(0.20) + A(0.79)$	=	$P(0.939)$
O ₂ :	$A(0.21)$	=	$P(0.012 + 0.049) + W\left(\frac{1}{2}\right) + C$

Step 9:

$A = 954.2 \text{ mol}$

$C = 70.1 \text{ mol}$

$P = 824.1 \text{ mol}$

$O_2 \text{ in} = 0.21A = 200.38$

$O_2 \text{ consumed} = \frac{1}{2}W + C + 0.012P = \frac{1}{2}(160) + 70.1 + 0.012(824.1) = 160 \text{ mol}$

$$\text{Excess } O_2 = \frac{O_2 \text{ in} - O_2 \text{ consumed}}{O_2 \text{ consumed}} = \left(\frac{200.382 - 160}{160} \right) \times 100 = 25.2\%$$

3.57

NO. The answer is not correct because the required O_2 calculation should be based on equations for complete combustion less the O_2 in the fuel. Here there are both O_2 in the air and O_2 in the fuel so the required O_2 must be reduced from 192.5 minus 5.0 = 187.5 mol.

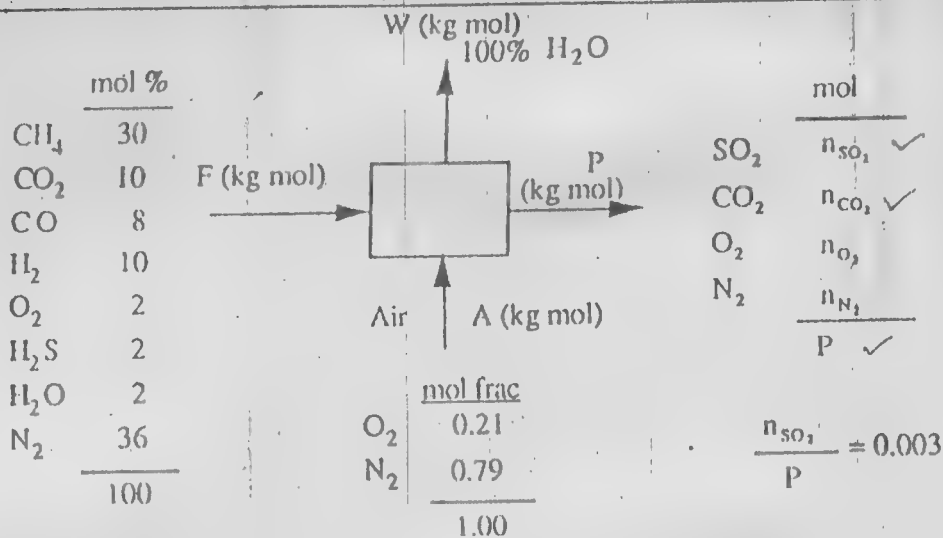
3.58

Assume a steady state process

Steps 1, 2, 3, and 4:

(continued)

Solutions - Chapter - 3



Step 5:

Basis: F = 100 kg mol

Step 6:

Unknowns: A, W, P, n_{CO₂}, n_{O₂}, n_{SO₂}, n_{N₂}

Total 7.

Step 7:

Balances: C, H, O, N, S, n_{SO₂} = 0.003 P, Σn_i = P

Steps 8 and 9:

Balances

N₂:

$$36 + A(0.79) = n_{N_2}$$

S (a tie component):

$$2 = n_{SO_2} \rightarrow P = \frac{2}{0.003} = 667 \text{ kg mol}$$

H:

$$30(4) + 10(2) + 2(2) + 2(2) = W(2) \rightarrow W = 74 \text{ kg mol}$$

C:

$$30(1) + 10(1) + 8(1) = n_{CO_2} \rightarrow n_{CO_2} = 48 \text{ kg mol}$$

O:

$$10(2) + 8(1) + 2(2) + 2(1) + 0.21A = n_{CO_2}(2) + n_{O_2}(2) + n_{SO_2}(2) + W(1)$$

Step 9:

From O eqn:

$$34 + 0.21A = 48(2) + 2n_{O_2} + 2(2) + 74$$

$$0.21A = 2n_{O_2} + 140$$

From N₂ eqn:

$$36 + 0.79A = n_{N_2}$$

From Σn_i = P:

$$667 = 48 + n_{O_2} + n_{N_2} + 2$$

$$617 = n_{O_2} + n_{N_2}$$

(continued)

$$617 = \frac{0.21A - 140}{2} + [36 + 0.79A]$$

$$= 0.105A - 70 + 36 + 0.79A$$

$$= 0.895A - 34$$

$$A = 727 \quad \checkmark$$

$$n_{N_2} = 610.6 \text{ kg mol}$$

$$n_{O_2} = \frac{0.21(727) - 140}{2} = 6.4 \text{ kg mol}$$

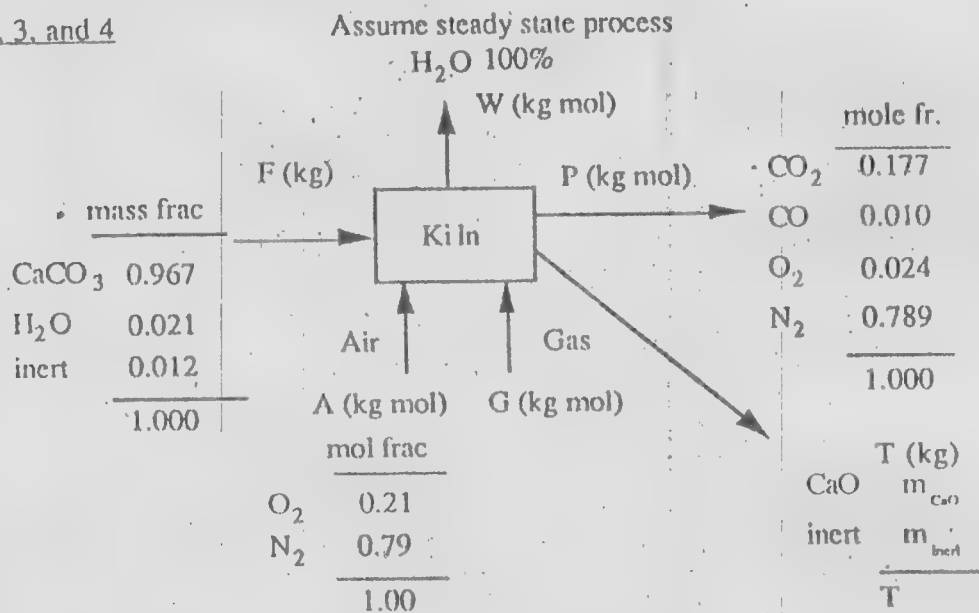
Orsat Analysis

	kg mol
CO ₂	48
O ₂	6.4
SO ₂	2
N ₂	610.6
	667

Orsat mol fr.
0.072
0.010
0.003
0.915
1.000

3.59

Steps: 1, 2, 3, and 4



Step 5:

Almost any basis will do. Pick the Basis: $P = 100 \text{ kg mol}$

Step 6:

Unknowns are W, F, G, T , and A , plus two unknown compositions in T , for a total of 7.

(continued)

Solutions - Chapter - 3

Step 7: Balances C, H, O, N, Ca, inert, $\sum m_i = T$ (total 7).
We may not need all of these if we do not have to solve for any stream but G and T.

Steps 8 and 9: Balances

$$\text{Ca (kg mol): } \frac{F(0.967) \text{ kg CaCO}_3}{100.09 \text{ kg CaCO}_3} \left| \frac{1 \text{ kg mol CaCO}_3}{1 \text{ kg mol Ca}} \right| =$$

$$\frac{m_{\text{CaO}} \text{ kg CaO}}{56.08 \text{ kg CaO}} \left| \frac{1 \text{ kg mol CaO}}{1 \text{ kg mol CaO}} \right|$$

$$\text{inert (kg): } F(0.012) \text{ kg} = m_{\text{inert}} \text{ kg}$$

$$\sum m_i = T \text{ (kg): } m_{\text{CaO}} + m_{\text{inert}} = T$$

$$\text{N}_2 \text{ (kg mol): } G(0.101) \text{ kg mol} + A(0.79) \text{ kg mol} = 78.9 \text{ kg mol}$$

$$\text{C (kg mol): } \frac{F(0.967)}{100.09 \text{ kg CaCO}_3} \left| \frac{1 \text{ kg mol CaCO}_3}{1 \text{ kg mol C}} \right| + G(0.801) + 2G(0.098)$$

$$= 0.177 + 0.010$$

$$\text{H (kg mol): } \frac{F(0.021) \text{ kg H}_2\text{O}}{18 \text{ kg H}_2\text{O}} \left| \frac{1 \text{ kg mol H}_2\text{O}}{1 \text{ kg mol H}_2\text{O}} \right| \frac{2 \text{ kg mol H}}{1 \text{ kg mol H}_2\text{O}}$$

$$+ G(0.801)(4) + G(0.098)(6) = W(2)$$

$$\text{O (kg mol): } \frac{F(0.967)}{100.09} \left| \frac{1}{1} \right| \frac{3}{1} + \frac{F(0.021)}{18} \left| \frac{1}{1} \right| \frac{1}{1} + A(0.21)(2)$$

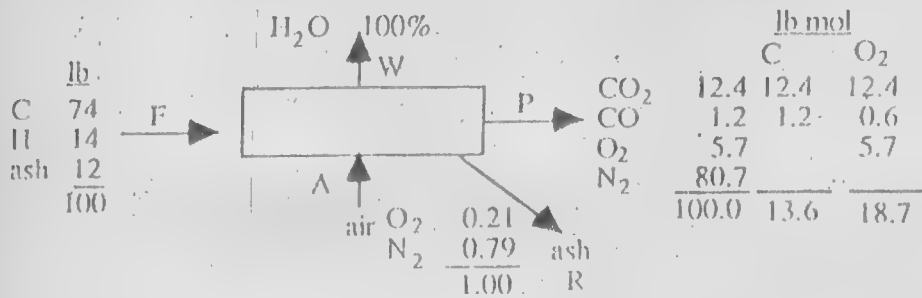
$$= W(1) + \frac{m_{\text{CaO}}}{56.08} \left| \frac{1}{1} \right| \frac{1}{1} + 1.0 + 2.4(2) + 17.7(2)$$

Second Basis: $F = 100 \text{ kg}$

$$\text{Ca (kg mol): } \frac{100(0.967)}{100.09} \left| \frac{1}{1} \right| \frac{1}{1} = \frac{m_{\text{CaO}}}{56.08}$$

$$m_{\text{CaO}} = 54.18 \text{ kg}$$

3.60



All compositions are known, four streams are unknown if you take a basis.

Basis: 100 lb mol flue gas (P)

You can make C, H, O, N and ash balances, hence problem has a unique solution if one balance is redundant; otherwise, not.

$$\text{C balance (lb): } 0.74F = (13.6) 12; F = 220.54 \text{ lb}$$

$$\text{O}_2 \text{ balance (lb mol): } 0.21 A = 18.7 + W (1/2)$$

$$\text{N}_2 \text{ balance (lb mol): } 0.79A = 80.7; A = 102.2 \text{ lb mol}$$

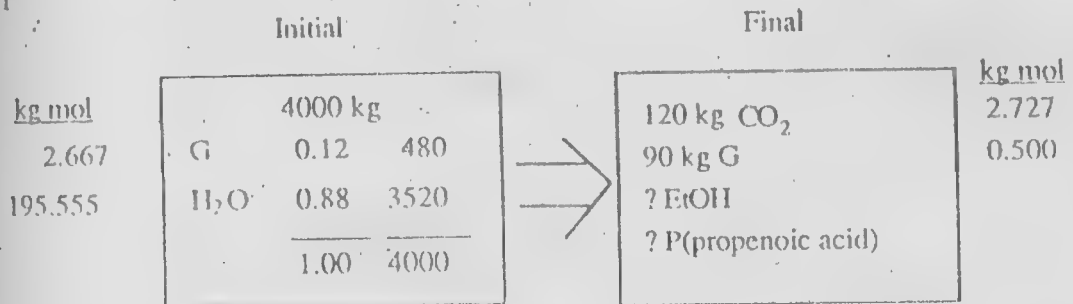
$$W = 2 [(0.21)(102.2) - 18.7] = 5.524 \text{ lb mol}$$

H₂ balance as check:

$$\frac{0.14(220.54)}{2(1.008)} = 15.3$$

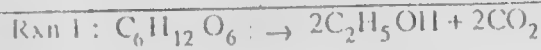
[NO] Some inconsistency exists.

3.61



Closed system, with rxn, unsteady state

(continued)



No. of Balances: G, H₂O, EtOH, P, CO₂.

⑤

No. of Unknown: n_{EtOH} , n_{P} , $n_{\text{H}_2\text{O}}$ ③ +
generation + consumption terms

mol wt	mol
C ₆ H ₁₂ O ₆ :G	180
C ₂ H ₅ OH: EtOH	46
CO ₂	44
H ₂ O	18
C ₂ H ₃ CO ₂ H:P	72

order used	balance	final	initial	generation	consumption
2	G	0.500	2.667	0	$n_{\text{G react}}$
3	EtOH	$n_{\text{EtOH final}}$	0	$n_{\text{EtOH generated}}$	0
1	CO ₂	2.727	0	$n_{\text{CO}_2 \text{ generated}}$	0
4	P	$n_{\text{P final}}$	0	$n_{\text{P generated}}$	0
5	H ₂ O	$n_{\text{H}_2\text{O}}$	195.555	$n_{\text{H}_2\text{O generated}}$	0

$$n_{\text{CO}_2 \text{ generated}} = 2.727$$

$$n_{\text{G reacted}} = 2.667 - 0.500 = 2.167$$

$$n_{\text{EtOH gen.}} = n_{\text{CO}_2 \text{ gen.}} \text{ using Eq. 1, } = 2.727$$

$$\text{no. mol G reacted by Eq. 1: } 1/2 (n_{\text{CO}_2}) = 1.364$$

$$\text{no. mol G reacted by Eq. 2: } 2.667 - 1.364 = 1.303$$

$$\text{no. mol P generated (by Eq. 2): } 2 (1.303) = 2.606$$

$$\text{no. mol H}_2\text{O generated} = n_{\text{P final}} = 2.606 \quad \times 18 = 46.91 \text{ lb}$$

$$\text{no. mol total H}_2\text{O out} = 195.555 + 2.606 = 198.16$$

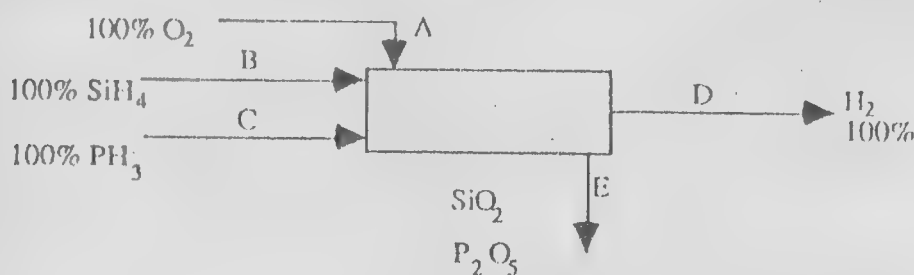
(continued)

final mixture				
Comp.	kg mol	mol wt	lb	%
CO ₂	2.727	44	119.9	2.93
G	0.500	180	90.0	2.20
EtOH	2.727	46	125.4	3.06
H ₂ O	198.18	18	3566.88	87.21
P	2.606	72	187.63	4.58
			4089.9	100.0

An alternate solution is to use element balances.

3.62

Steps 1, 2, 3 and 4:



Step 5: Basis: 1 g mol PH₃

Step 6: No. Unknowns: A, B, D, E, $n_{P_2O_5}^E$ (5)

Step 7: Balances: Si, H, P, O, $\omega_P^E = 0.05$ (5)

Note: $n_{P_2O_5}^E + n_{SiO_2}^E = E$

Steps 8 and 9:

P Bal: in

$$\left. \begin{array}{l} \frac{1 \text{ g mol PH}_3}{1 \text{ g mol PH}_3} \left| \frac{0.5 \text{ g mol P}_2\text{O}_5}{1 \text{ g mol PH}_3} \right| \frac{2 \text{ g mol P}}{1 \text{ g mol P}_2\text{O}_5} \left| \frac{31 \text{ g P}}{1 \text{ mol P}} \right| = 31 \text{ g P} \\ \frac{1 \text{ g mol PH}_3}{1 \text{ g mol PH}_3} \left| \frac{0.5 \text{ g mol P}_2\text{O}_5}{1 \text{ g mol PH}_3} \right| \frac{5 \text{ g mol O}}{1 \text{ g mol P}_2\text{O}_5} \left| \frac{16 \text{ g O}}{1 \text{ g mol O}} \right| = 40 \text{ g O} \end{array} \right\} \text{in P}_2\text{O}_5$$

(continued)

Si Bal:

$$\frac{B \text{ g mol SiH}_4}{1 \text{ g mol SiH}_4} \left| \frac{1 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \right| \frac{1 \text{ g mol Si}}{1 \text{ g mol SiO}_2} \left| \frac{28.1 \text{ g Si}}{1 \text{ g mol Si}} \right| = 28.1 B \text{ g Si}$$

$$\frac{B \text{ g mol SiH}_4}{1 \text{ g mol SiH}_4} \left| \frac{1 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \right| \frac{2 \text{ g mol O}}{1 \text{ g mol SiO}_2} \left| \frac{16 \text{ g O}}{1 \text{ g mol O}} \right| = 32 B \text{ g O}$$

Total: $71 + 60.1B$

$$\frac{31}{71 + 60.1B} = 0.05$$

$$3.55 + 3.0058B = 31$$

$$B = 9.13 \text{ g mol r}$$

$$\frac{1 \text{ g mol PH}_3}{1 \text{ g mol PH}_3} \left| \frac{34 \text{ g PH}_3}{1 \text{ g mol PH}_3} \right| = 34 \text{ g PH}_3$$

Basis 3 g mol of PH₃ or 34 g of PH₃

$$\text{wt. of P}_2\text{O}_5 \text{ produced} = \frac{2(142)}{4(34)} \times 34 = 71 \text{ g}$$

$$\text{wt. of SiO}_2 \text{ produced} = \frac{1(60)}{1(32)} \times B = 1.875B$$

$$\frac{9.13 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \left| \frac{32.1 \text{ g SiH}_4}{1 \text{ g mol SiH}_4} \right| = 293 \text{ g SiO}_2$$

$$\text{So } E = 71 \text{ g} + 1.875B$$

Now as P is entering 31 g and it constitutes 5% of P deposited on plate so it is rep. of

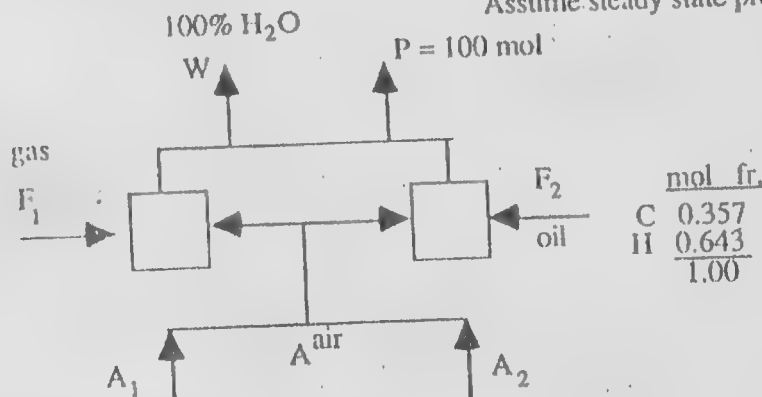
$$\frac{293}{34} = 8.62 \frac{\text{g SiO}_2}{\text{g PH}_3}$$

$$\frac{31}{71 + 1.875B} = 5\%$$

$$B = 293.5$$

3.63

Assume steady state process



Basis: 100 mol natural gas

Comp.	mol = %	atoms C	atoms O	atoms H
CH ₄	96	96	--	384
C ₂ H ₂	2	4	--	4
CO ₂	2	2	4	--
Total	100	102	4	388

(continued)

Basis: 100 mol oil

Comp.	atoms C	atoms H
$(C_{11}H_{1.8})_n$	100	180

Basis: 100 mol flue gas (dry)

Comp.	mol%	mol C	mol O	atoms H	mol N ₂
CO ₂	10.0	10.00	20.00	--	
CO	0.63	0.63	0.63	--	
O ₂	4.55	--	9.10	--	
N ₂	84.82	--	--	--	84.82
Total	100.00	10.63	29.73	--	84.82

Note: If have separate air streams, we have 5 unknowns and can't solve.

Basis: 100 mol natural gas (or use 100 mol dry gas product.)

Let F_2 = mol oil F_1 or P = mol dry flue gas A = mol air, to natural gas fed boiler plus oil fed boiler W = mol water associated with the dry flue gas

Four balances: In = Out

C balance

$$102 + F_2 = 0.1063 P \quad (1)$$

N₂ balance

$$0.79A = 0.8482 P \quad (2)$$

H balance

$$388 + 1.80 F_2 = 2 W \quad (3)$$

O balance

$$4 + 0.42A = 0.2973P + W \quad (4)$$

$$P = 1729 \text{ mol dry flue gas}$$

$$W = 268 \text{ mol H}_2\text{O}$$

$$F_2 = 82 \text{ mol oil and 1 mol C} = 1 \text{ mol oil so}$$

(continued)

Solutions - Chapter - 3

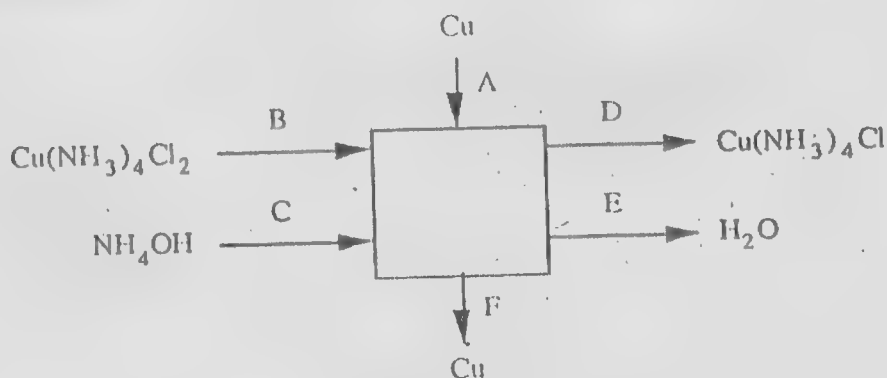
$$\text{C in oil} = F_2 = 82 \text{ mol}$$

$$\text{Total C} = 102 + 82 = 184 \text{ mol}$$

$$\% \text{ C burned from oil} = \frac{(0.82)(100)}{184} = \boxed{44.5\%}$$

3.64

Steps 1, 2, 3 and 4:



Step 5:

Basis: 1 board

$$\text{A: Cu foil} \quad \frac{4 \text{ in} \times 8 \text{ in} \times 0.03 \text{ in}}{\text{in}^3} \times \frac{(2.54 \text{ cm})^3}{\text{in}^3} \times \frac{8.96 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ g mol Cu}}{63.55 \text{ g Cu}} = 2.219 \text{ g mol Cu}$$

$$\text{F: Cu remaining} \quad \frac{1 - 0.75}{1} \times \frac{2.219 \text{ g mol Cu}}{1} = 0.555 \text{ g mol Cu}$$

Steps 6 and 7: Unknowns: B, C, D, E

Balances: Cu, N, Cl, H, O should be enough if one is redundant

Steps 8 and 9: (Balances to be solved:)

Cu Balance:

$$2.219 \text{ g mol Cu} + \frac{B \text{ g mol Cu(NH}_3)_4 \text{Cl}_2}{1 \text{ g mol Cu(NH}_3)_4 \text{Cl}_2} \times \frac{1 \text{ g mol Cu}}{1 \text{ g mol Cu(NH}_3)_4 \text{Cl}_2}$$

$$= 1.664 \text{ g mol Cu} + \frac{D \text{ g mol Cu(NH}_3)_4 \text{Cl}}{1 \text{ g mol Cu(NH}_3)_4 \text{Cl}} \times \frac{1 \text{ g mol Cu}}{1 \text{ g mol Cu(NH}_3)_4 \text{Cl}}$$

(continued)

Cl Balance:

$$\frac{B \text{ g mol Cu(NH}_3)_4 \text{ Cl}_2}{\text{g mol Cu(NH}_3)_4 \text{ Cl}_2} \left| \frac{2 \text{ g mol Cl}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}_2} \right| = \frac{D \text{ g mol Cu(NH}_3)_4 \text{ Cl}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}} \left| \frac{1 \text{ g mol Cl}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}} \right|$$

N Balance:

$$\frac{B \text{ g mol Cu(NH}_3)_4 \text{ Cl}_2}{\text{g mol Cu(NH}_3)_4 \text{ Cl}_2} \left| \frac{4 \text{ g mol N}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}_2} \right| + \frac{C \text{ g mol NH}_4\text{OH}}{\text{g mol NH}_4\text{OH}} \left| \frac{1 \text{ g mol N}}{\text{g mol NH}_4\text{OH}} \right|$$

$$= \frac{D \text{ g mol Cu(NH}_3)_4 \text{ Cl}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}} \left| \frac{4 \text{ g mol N}}{\text{g mol Cu(NH}_3)_4 \text{ Cl}} \right|$$

Solution:

Cu overall: $A + B = F + D \rightarrow A + B = F + (2B)$

$$2.219 + B = 0.555 + (2B)$$

$$B = 2.219 - 0.555 = 1.664 \text{ g mol Cu(NH}_3)_4 \text{ Cl}_2$$

Cl: $D = 2B = 2(1.664) = 3.328 \text{ g mol Cu(NH}_3)_4 \text{ Cl}$

N: $4B + C = 4D$

$$C = 4(D - B) = 4(3.328 - 1.664) = 6.656 \text{ g mol NH}_4\text{OH}$$

MW of NH₄OH

N	14
H ₄	4
O	16
H	1
	35

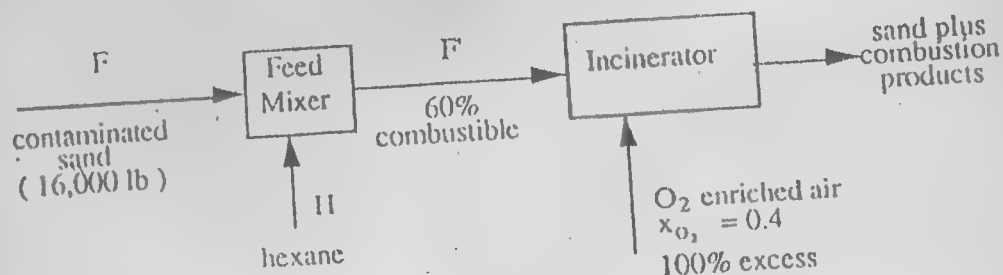
$$\frac{35 \text{ g NH}_4\text{OH}}{\text{g mol}} \left| \frac{6.656 \text{ g mol}}{\text{g mol}} \right| = \boxed{232.0 \text{ g NH}_4\text{OH}}$$

Cu(NH₃)₄Cl₂

Cu	63.55
N	56.00
H	12.00
Cl ₂	70.90
	202.45

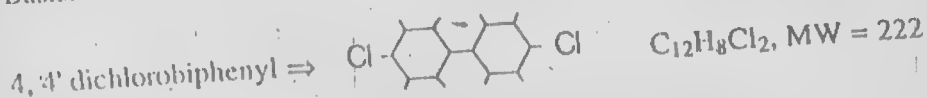
$$202.45 \text{ (g/gmol)} (1.664 \text{ g mol}) = \boxed{336.88 \text{ g Cu(NH}_3)_4 \text{ Cl}_2}$$

3.65



a)

Basis: 8 tons of contaminated sand containing 30% PCB



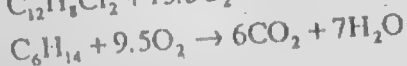
$$\frac{8 \text{ tons sand + PCB}}{\text{ton sand + PCB}} \left| \frac{0.3 \text{ ton PCB}}{\text{ton sand + PCB}} \right| \left| \frac{2000 \text{ lb PCB}}{\text{ton PCB}} \right| = 4800 \text{ lb PCB}$$

If we want the net feed to be 60% combustible, we see that the sand is a tie component:

A sand balance around the feed mixer: $16000(0.7) = F'(0.4)$ so $F' = 28,000 \text{ lb}$.

A total balance around the feed mixer: $F + H = F' \Rightarrow H = 12,000 \text{ lb}_m \text{ hexane}$

b)

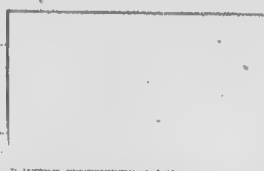


Even with total combustion, we will produce undesirable HCl which will adversely affect the environment if it is simply vented. Therefore, it would be wise to condense the HCl and H_2O by cooling. Perhaps the acid solution might be sold to help pay for the process.

(continued)

c)

21.62 moles PCB

139.5 moles nC_6 

P

16.54% CO_2 12.20% O_2 $H_2O = ?$ $HCl = ?$ $N_2 = ?$

enriched air

(40% O_2 , 60% N_2)By a tie component for CO_2 , we know:

$$12(21.62) + 139.5(6) = 0.1654 P \text{ hence } P = 6629 \text{ mol}$$

By an O tie: $0.40(2)A = 0.1654(2)(6629) + 0.1220(2)(6629) + x_{H_2O}(1)(6629)$

$$x_{H_2O}(6629) = \frac{21.62 \text{ PCB Reacted} \left| \frac{3H_2O}{1 \text{ PCB}} \right| + 139.6 \text{ C}_6 \text{ Reacted} \left| \frac{7H_2O}{1 \text{ C}_6} \right|}{1} = 1042$$

$$\text{so } x_{H_2O} = 0.1572$$

From O tie balance: $A = 6065.4 \text{ mol of } 40\% O_2 \text{ air}$ Thus: $(N_2)_{in} = (N_2)_{out} = 0.6(6065.4) = 3639.2 \text{ mol } N_2$

$$x_{N_2} = \frac{3639.2}{6629.0} = 0.549$$

We can get HCl by a Cl balance: $\frac{21.6 \text{ PCB Reacted} \left| \frac{2HCl}{1 \text{ PCB}} \right|}{1} = 43.2 \text{ mol HCl in product}$

$$x_{HCl} = 0.0065$$

Product
Composition

Component	x_i
CO_2	0.1654
O_2	0.1220
H_2O	0.1572
HCl	0.0065
N_2	0.5490

We know % excess O_2 used is : % excess = $\frac{100[O_2 \text{ fed} - O_2 \text{ req'd}]}{(O_2 \text{ req'd})}$

(continued)

$$O_2 \text{ fed} = 0.4 (\text{air fed}) = 0.4 (6065.4) = 2426.2 \text{ mol } O_2$$

Also, since we have total combustion,

$$(O_2 \text{ req'd}) = (O_2 \text{ consumed}) = (O_2 \text{ fed} - O_2 \text{ out}) = 2426.2 - 0.1220(6629) \\ = 1617.5 \text{ moles req'd}$$

$$\text{Thus: } \% O_2 = 100 \left(\frac{2426.2 - 1617.5}{1617.5} \right) = \boxed{50\% \text{ excess } O_2 \text{ used}}$$

3.66

Basis: 100 moles exhaust gas

Comp	exhaust gas mol		exit gas %	mol
CO ₂	16.2	tie element	13.1	16.2
O ₂	4.8			
N ₂	79.0	83.8	86.9	107.4
Total	100.0		100.0	123.6

$$\frac{16.2 \text{ mol CO}_2}{100.0 \text{ mol exhaust gas}} \bigg| \frac{100.0 \text{ mol exit gas}}{13.1 \text{ mol CO}_2} = 123.6 \text{ mol exit gas}$$

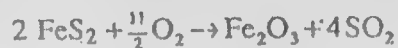
$$\text{exhaust gas} = \underline{100.0 \text{ mol}}$$

$$\text{air leaked in} = 23.6 \text{ mol}$$

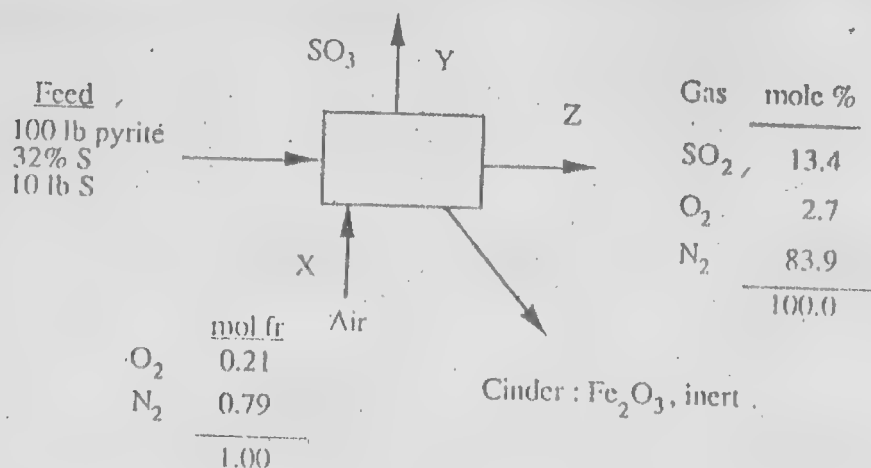
$$\frac{23.6}{100.0} = \boxed{0.236 \text{ mol air / mol exhaust gas}}$$

3.67

Basis: 100 lb pyrites in



(continued)



Let X = mol air in, Y = mol SO₃ out, Z = mol flue gas out

1. Sulfur Balance: $(32 + 10)/32 = Y + 0.134Z$

2. O₂ Balance: $0.21X = 1.5Y + (0.134 + 0.027)Z$

$$+ \frac{1 \text{ mol S}}{2 \text{ mol S}} \left| \frac{\text{mol Fe}}{2 \text{ mol Fe}} \right| \frac{1 \text{ mol Fe}_2\text{O}_3}{2 \text{ mol Fe}} \left| \frac{1.5 \text{ mol O}_2}{1 \text{ mol Fe}_2\text{O}_3} \right|$$

3. N₂ Balance: $0.79X = 0.839Z$

Solve (1), (2), (3): Y = 0.118 mol, Z = 8.9 mol

Check: mol S = 0.118 + 0.134(8.9) = 1.31

% conversion of S to SO₃ = $(11.8)/(1.315) = \boxed{8.98\%}$

3.68

Six independent equations. The sum of the components (in moles) would equal the total flow, hence not all of the equations that could be written would be independent, only 2 per subsystem.

Total balances:

Condenser

$F_2 = F_4 + F_5$ (F₃ does not mix, hence cancels out or can be omitted)

Column

$F_1 + F_5 + F_9 = F_2 + F_8$

(continued)

Reboiler

$F_8 = F_9 + F_7$ (F_6 does not mix, hence cancels out or can be omitted)

Component balances:

In addition, component balances could be written for each component for each subsystem.

3.69

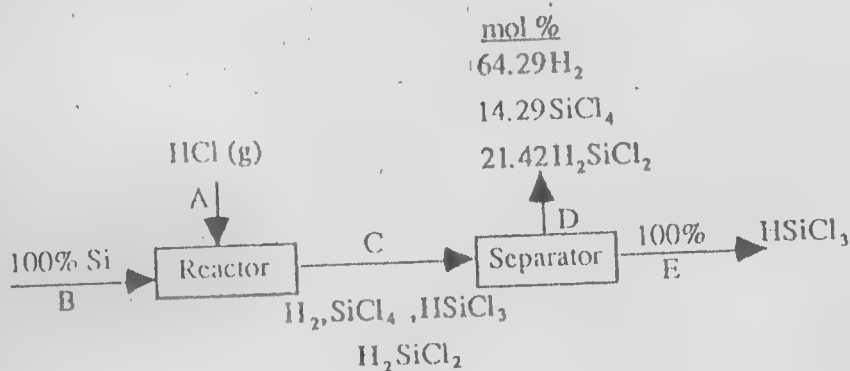
Unknowns: C, D, E, F, G, H, x_{F,C_1} , x_{F,C_2} (8 total)

Balances:	Unit 1	3	C_2, C_3, C_4
	Unit 2	2	C_2, C_3
	Unit 3	3	C_2, C_3, C_4
		8	

Note: $1 - x_{F,C_1} - x_{F,C_2} = x_{F,C_3}$ can be included as 1 more equation and one more unknown (x_{F,C_3}).

3.70

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 kg B

$$\frac{100 \text{ kg Si}}{28.09 \text{ kg Si}} \times \frac{1 \text{ kg mol Si}}{1} = 3.560 \text{ kg mol Si}$$

Steps 6 and 7: Unknowns: A, D, E

Balances: H, Cl, Si

Steps 8 and 9: Balances to be solved:

(continued)

Si overall mole balance

$$\text{kg mol Si} = 3.560$$

$$= D \text{ kg mol gas} \left[\frac{0.1429 \text{ kg mol SiCl}_4}{\text{kg mol gas}} \right] \frac{1 \text{ kg mol Si}}{\text{kg mol SiCl}_4} + \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{1 \text{ kg mol Si}}{\text{kg mol H}_2\text{SiCl}_2} \right] \\ + \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{1 \text{ kg mol Si}}{\text{kg mol HSiCl}_3} \right] = 0.3571D + E$$

Cl overall mol balance

$$\frac{A \text{ kg mol HCl}}{\text{kg mol HCl}} \left[\frac{1 \text{ kg mol Cl}}{\text{kg mol HCl}} \right] = D \text{ kg mol gas} \left[\frac{0.1429 \text{ kg mol SiCl}_4}{\text{kg mol gas}} \right] \frac{4 \text{ kg mol Cl}}{\text{kg mol SiCl}_4} \\ + \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{2 \text{ kg mol Cl}}{\text{kg mol H}_2\text{SiCl}_2} \right] + \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{3 \text{ kg mol Cl}}{\text{kg mol HSiCl}_3} \right]$$

$$A = D + 3E$$

H overall mol balance

$$\frac{A \text{ kg mol HCl}}{\text{kg mol HCl}} \left[\frac{1 \text{ kg mol H}}{\text{kg mol HCl}} \right] = D \text{ kg mol gas} \left[\frac{0.6429 \text{ kg mol H}_2}{\text{kg mol gas}} \right] \frac{2 \text{ kg mol H}}{\text{kg mol H}_2} \\ + \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{2 \text{ kg mol H}}{\text{kg mol H}_2\text{SiCl}_2} \right] + \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{1 \text{ kg mol H}}{\text{kg mol HSiCl}_3} \right]$$

$$A = 1.7142D + E$$

$$\text{Solution: } 3.560 = 0.3571 D + E \quad (1)$$

$$A = D + 3E \quad (2)$$

$$A = 1.7142D + E \quad (3)$$

$$(2) - (3) \quad 2E = 0.7142 D$$

(continued)

$$E = 0.3571 D \quad (4)$$

$$(1) (4) \rightarrow 3.56 = 0.3571 D + 0.3571 D$$

$$D = 4.9846$$

$$E = 1.7800$$

$$A = 10.3246$$

	MW
H	1.01
Si	28.09
Cl ₃	106.35
	135.45 kg/mol

$$\frac{135.45 \text{ kg HSiCl}_3}{\text{kg mol HSiCl}_3} \times \frac{1.78 \text{ kg mol}}{\text{kg mol HSiCl}_3} = \boxed{241.1 \text{ kg HSiCl}_3}$$

3.71

Solution

Steps: 1, 2, 3, and 4: This is a steady state process with no reaction taking place. All the compositions are known. We can pick the overall system first to get D, and then make balances on the first (or second) units to get C and its composition.

Step 5: Basis: $F = 290 \text{ kg}$ (equivalent to 1 second)

Step 6: Unknowns: A, B, C, D and E (5 total) overall

Step 7: Balances: NaCl, HCl, H₂SO₄, H₂O, inert solid (5 total) overall

Overall balances (kg)

	In		Out
NaCl:	A(0.040)	=	290(0.0138)
HCl:	A(0.050)	=	290(0.0255)+D(0.020)+E(0.015)
H ₂ SO ₄ :	A(0.040)	=	290(0.0221)+D(0.020)+E(0.015)
H ₂ O:	A(0.870)+B(0.910)	=	290(0.9232)+D(0.960)+E(0.970)
Inerts:	B(0.09)	=	290(0.0155)
Totals:	A + B	=	D + E + 290

From these equations, we can get A and B directly, and then solve two of the equations for D and E.

Once A, B, D and E are known, C and its components can be calculated directly, say by a set of 5 balances on the first unit.

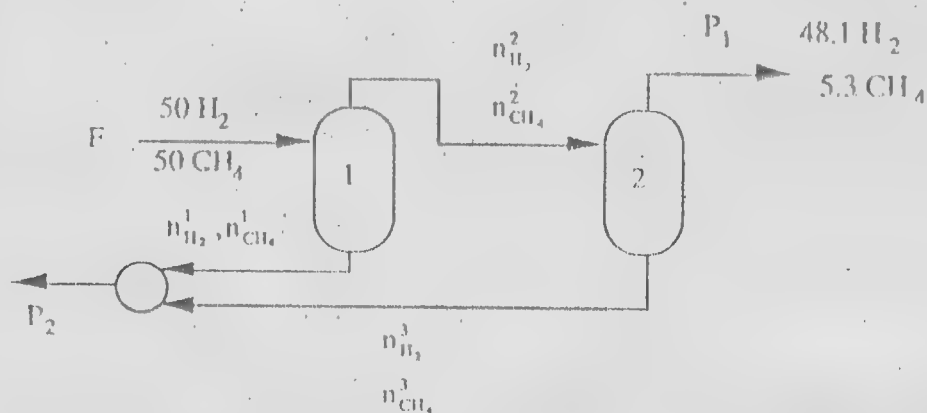
The solution to the problem should give (in kg)

(continued)

Comp	A	B	C	D	E	
NaCl	4.0		4.0			
HCl	5.0		5.0	1.20	1.20	
H ₂ SO ₄	4.0		4.0	1.20	1.20	
H ₂ O	87.0	45.4	132.5	57.6	77.6	2
Inerts		4.5	4.5			
Total:	100.00	50.0	150.0	60.0	80.0	2

3.72

Steps 1, 2, 3 and 4:



Assume steady state process, no reaction.

Step 5: Basis 100 mol gas in ($F = 100$)

Step 6: 6 unknowns

Step 7, 8 and 9:

	In		Out
Unit 1			
H ₂ :	50	=	$n_{H_2}^1 + n_{H_2}^2$
CH ₄ :	50	=	$n_{CH_4}^1 + n_{CH_4}^2$

Unit 2			
H ₂ :	$n_{H_2}^2$	=	$48.1 + n_{H_2}^3$
CH ₄ :	$n_{CH_4}^2$	=	$5.3 + n_{CH_4}^3$

Mixing Point

H ₂ :	$n_{H_2}^1 + n_{H_2}^3$	=	1.9
CH ₄ :	$n_{CH_4}^1 + n_{CH_4}^3$	=	44.7

(cont)

$$50 = n_{H_2}^1 + 48.1 + n_{H_2}^3$$

$$50 = n_{CH_4}^1 + 5.3 + n_{CH_4}^3$$

These equations reduce to

$$n_{H_2}^1 + n_{H_2}^3 = 1.9 \quad (A)$$

$$n_{CH_4}^1 + n_{CH_4}^3 = 44.7 \quad (B)$$

a) We have 6 variables but we do not have 6 independent equations.

b) Assume $n_{H_2}^3 = 0.3$

$$n_{H_2}^1 + 0.3 = 1.9$$

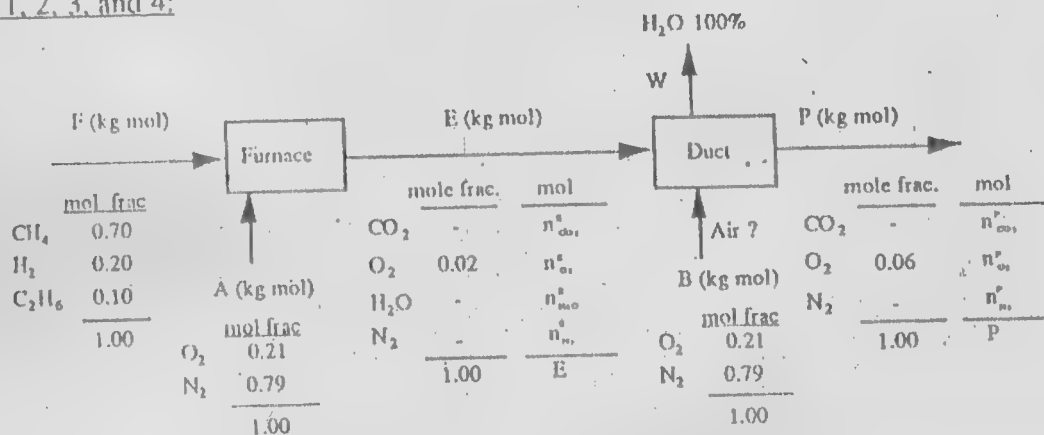
We can therefore solve for $n_{H_2}^1$, but not for $n_{CH_4}^1$ or $n_{CH_4}^3$.

c) If $n_{H_2}^3 = 0.3$ mol and $n_{CH_4}^3 = 6.8$ mol then we can solve for all variables.

3.73

Step 5: Basis: 100 kg mol = F

Steps 1, 2, 3, and 4:



Assume an air leak occurs first and use material balances to calculate the amount. This is a steady state flow process without reaction.

Overall system

Step 6:

Unknowns are: A, B, W, P, x_{N_2} (or n_{N_2}), x_{CO_2} (or n_{CO_2})

(continued)

Step 7: Balances are: C, H, O, N, $\sum x_i^P = 1$ (or $\sum n_i^P = P$)

Steps 8 and 9:

	In		Out
C(kg mol):	$0.70(100) + 0.10(100)(2)$	=	n_{CO_2}
	$n_{CO_2} = 90 \text{ kg mol}$		
H(kg mol):	$0.70(100)(4) + 0.20(100)(2)$ $+ 0.10(100)(6)$	=	$W(2)$
	$W = 190 \text{ kg mol}$		
O ₂ (kg mol):	$0.21A + 0.21B$	=	$\frac{190(1.00)}{2} + 90 + 0.06P$
N ₂ (kg mol):	$0.79A + 0.79B$	=	$n_{N_2}^P$
	$90 + 0.06P + n_{N_2}^P$	=	P

A balance about the furnace or about the duct is needed; or these two alone would have been sufficient, omitting the overall balance.

System: Furnace (or Duct)

Step 6: Unknowns: $A, E, n_{CO_2}^E, n_{O_2}^E, n_{H_2O}^E$

Step 7: Balances: C, H, O, N₂, $\sum n_i^E = E$

Steps 8 and 9:

C(kg mol):	$0.70(100) + 0.10(100)(2)$	=	$n_{CO_2}^E$
	$n_{CO_2}^E = 90 \text{ kg mol}$		
H(kg mol):	$0.70(100)(4) + 0.20(100)(2) + 0.10(100)(6)$	=	$n_{H_2O}^E$
	$n_{H_2O}^E = 190$		
O ₂ (kg mol):	$0.21A$	=	$n_{O_2}^E + 90 + \frac{190}{2}$
N ₂ (kg mol):	$0.79A$	=	$n_{N_2}^E$
	$90 + 190 + n_{O_2}^E + n_{N_2}^E$	=	E

(continued)

$$0.02 = n_{O_2}^r / E$$

Solution:

	<u>kg mol in E</u>		<u>kg mol</u>
$n_{CO_2}^E$	90	A	982
$n_{H_2O}^E$	190	E	1077
$n_{O_2}^E$	21.5		
$n_{N_2}^E$	$\frac{776}{1077.5}$		

From the overall N_2 balance: $0.79(982) + 0.79B = n_{N_2}^P$ (1)

O_2 balance: $0.21(982) + 0.21B = 185 + 0.06P$ (2)

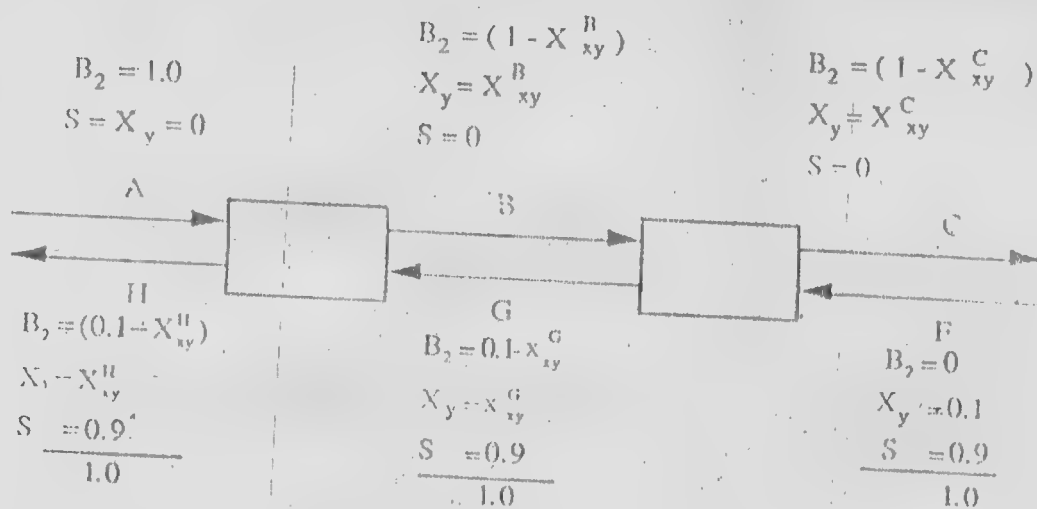
(1) $22.2 + 0.21B = 0.06P$ $B = 207 \text{ kg mol}$

(3) $90 + (0.79)(982) + 0.79B = 0.94P$ $P = 1095 \text{ kg mol}$

207 kg mol / 100 kg mol F



3.74



Unknowns: $B, C, G, H, X_{xy}^B, X_{xy}^C, X_{xy}^G, X_{xy}^H$

Balances:

Unit 1:

B_2, X_y, S

overall

Unit 2:

B_2, X_y, S

overall

$X_{xy}^B = 10X_{xy}^H$ & $X_{xy}^C = 10X_{xy}^G$
 All mass balance are in kg

Unit 1

Total $1000 + G = B + H$ - (1)

Benzene $1000(1) + (0.1 - X_{xy}^G)G = (1 - 10X_{xy}^H)B + (0.1 - X_{xy}^H)H$ - (2)

Xylene $0 + X_{xy}^G G = 10X_{xy}^H B + X_{xy}^H H$ - (3)

Solids $0 + 0.9G = 0 + 0.9H$ - (4)

Unit 2

Total $B + 2000 = C + G$ - (5)

Benzene $(1 - 10X_{xy}^H)B + 0 = (1 - 10X_{xy}^G)C + (0.1 - X_{xy}^G)G$ - (6)

Xylene $10X_{xy}^H B + 2000(0.1) = 10X_{xy}^G C + X_{xy}^G G$ - (7)

Solids $0 + 0.9F = 0.9G$

(continued)

Solving Equations

$$G = H = 2000$$

$$B = C = 1000$$

Substituting in (3)

$$2000 X_{ay}^G = 10,000 X_{ay}^H + 2000 X_{ay}^H$$

$$\text{so that } X_{ay}^G = 6X_{ay}^H \quad (9)$$

Substituting in (7)

$$10,000 X_{ay}^H + 200 = 60,000 X_{ay}^H + 12,000 X_{ay}^H$$

$$62,000 X_{ay}^H = 200$$

$$X_{ay}^H = \frac{1}{310} = 0.003$$

$$X_{ay}^G = 6X_{ay}^H = 0.018$$

$$X_{ay}^H = 10X_{ay}^H = 0.03$$

$$X_{ay}^C = 10X_{ay}^G = 0.18$$

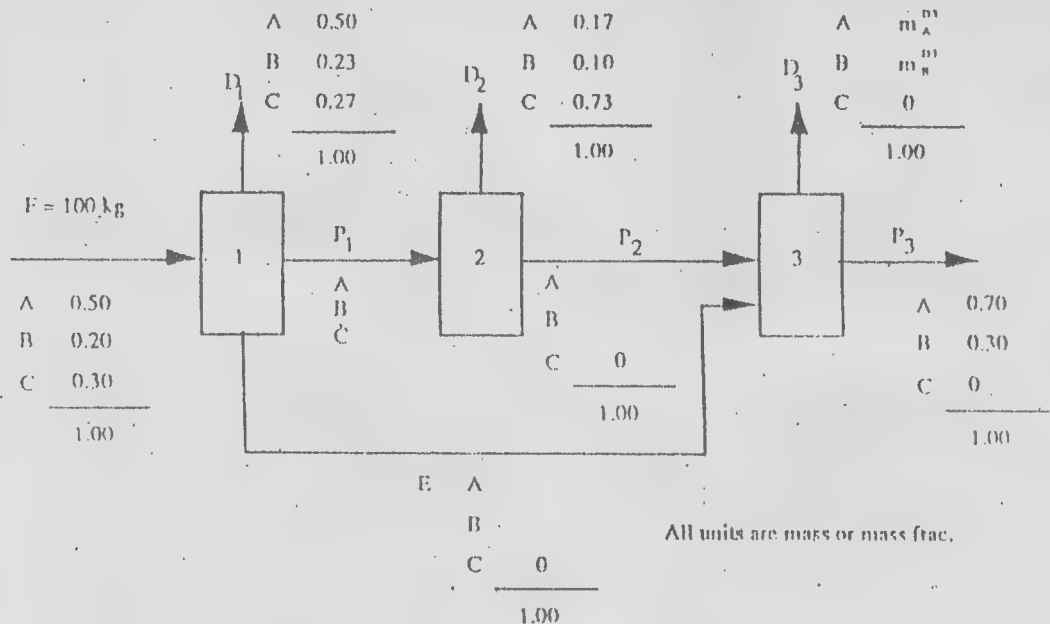
Stream	Component wt fr	Stream	Component wt fr
A	Bz 1.0 Xy 0.0	F	Bz 0.9 Xy 0.1
B	Bz 0.97 Xy 0.03	G	Bz 0.082 Xy 0.018
C	Bz 0.82 Xy 0.18	H	Bz 0.097 Xy 0.003

$$b) \quad \text{Xylene in Feed} = 2000 \times 0.1 = 200 \text{ kg}$$

$$\text{Xylene in Product C} = 1000 \times 0.18 = 180 \text{ kg}$$

$$\boxed{\% \text{ Recovery}} = \frac{180}{200} \times 100 = \boxed{90\%}$$

3.75



Additional information:

$$P_3 = 3D_3 = 30 \text{ kg}$$

$$P_2 = D_2$$

$$m_A^{P_2} = 4 m_B^{P_2}$$

Overall balances

$$\text{Total: } 100 = D_1 + D_2 + 10 + 30 \quad \text{or } 60 = D_1 + D_2$$

$$\text{C: } 100(0.30) = 0.27D_1 + 0.73D_2 + 0$$

Solve these two equations to get $D_1 = 30$ and $D_2 = 30$ Get $m_A^{D_1}$ and $m_B^{D_1}$ from A balance and $m_A^{D_1} + m_B^{D_1} = 1$

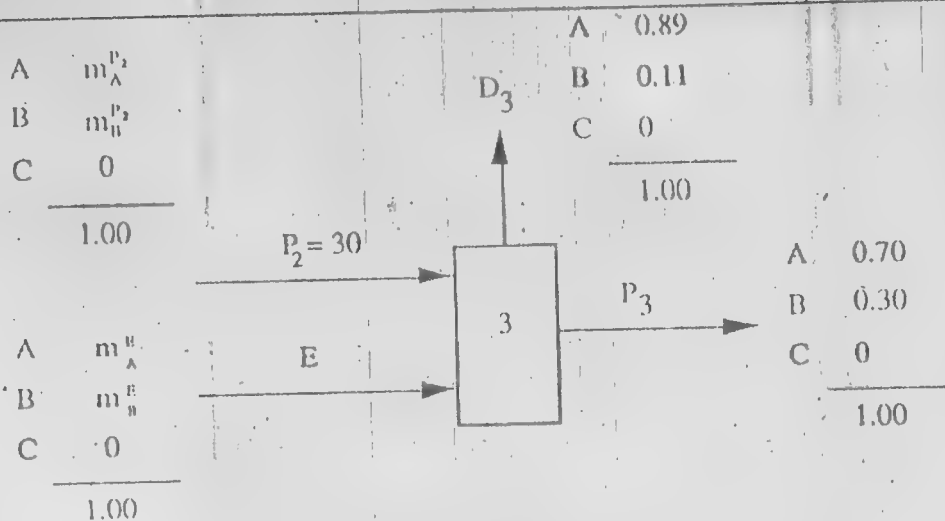
$$\text{A: } 100(0.50) = 30(0.50) + 30(0.17) + 10m_A^{D_1} + 30(0.70) \text{ so, } m_A^{D_1} = 0.89$$

$$\Sigma m_i = 1: \quad m_A^{D_1} + m_B^{D_1} = 1 \quad \text{so} \quad m_B^{D_1} = 0.11$$

Note - Can check using the B balance (not independent)

Balances on Unit No. 3

(continued)



Total: $30 + E = D_3 + P_3 = 10 + 30 = 40$ so $E = 10 \text{ kg}$

$A: 30 m_A^{P_2} + 10 m_A^E = 10(.89) + 30(.70) = 29.9$
 $B: 30 m_B^{P_2} + 10 m_B^E = 10(.11) + 30(.30) = 10.1$

} not independent equations

$\Sigma m_i^{P_2} = m_A^{P_2} + m_B^{P_2} = 1$
 $m_A^{P_2} = 4 m_B^{P_2}$

$m_A^{P_2} = 0.80$
 $m_B^{P_2} = 0.20$

so that

$30(.80) + 10 m_A^E = 29.9$ so that $m_A^E = 0.59$

$m_A^E + m_B^E = 1$ $m_B^E = 0.41$

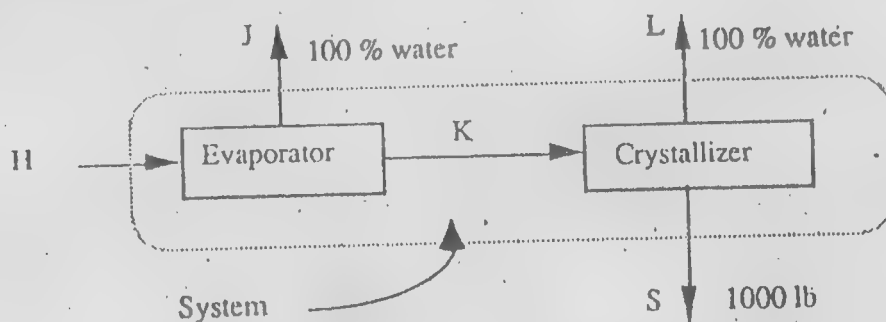
1.00

or 59%

or 41%

3.76

Pick evaporation and crystallizer as system.



(continued)

$$\left(\begin{array}{l} \text{Unknowns: } H, J, L \\ \text{Balances: } S, W \end{array} \right)$$

Not enough balances

So pick crystallizer alone first as system

$$\text{Total: } K = L + 1000$$

$$\text{Sugar: } K (0.40) = L (0) + 1000 (1.000)$$

$$\therefore K = 2500 \text{ lb/hr}$$

$$L = 1500 \text{ lb/hr}$$

a) Then pick Evaporator as the system

$$\text{Total: } H = J + K = J + 2500$$

$$\text{Sugar: } H (0.15) = J (0) + 2500 (0.40)$$

$$H = 6666.7 \text{ lb/hr}$$

$$J = 4166.7 \text{ lb/hr}$$

b) Screen as the system

$$\text{Total: } E = G + H = G + 6666.7$$

$$\text{Pulp: } E (0.14) = G (0.95) + H (0)$$

$$G = 1152.3 \text{ lb/hr}$$

$$E = 7819.0 \text{ lb/hr}$$

Use a sugar balance to get composition.

$$\text{Sugar: } E (0.13) = H (0.15) + G (x_s^G)$$

$$7819 (0.13) = 6666.7 (0.15) + 1152.3 (x_s^G)$$

$$(x_s^G) = 0.0143$$

$$(x_w^G) = 0.05 - 0.0143 = 0.0357$$

c) Then let the mill be the system

$$\text{Total: } F = E + D$$

$$\text{Pulp: } F (0.59) = 7819.0 (0.14) + D (0.80)$$

(continued)

$$\begin{aligned} F &= 24,574 \text{ lb / hr} \\ D &= 16,755 \text{ lb / hr} \end{aligned}$$

d) Sugar balance around mill:

$$0.16F = \omega_{\text{sugar, D}} D + 0.13 E$$

$$\begin{aligned} \omega_{\text{sugar, D}} D &= (0.16)(24,574) - 0.13(7,819) \\ &= 2,915 \text{ lb sugar/hr} \end{aligned}$$

$$\frac{2,915 \text{ lb / hr}}{(0.16)(24,574) \text{ lb / hr}} (100) = \boxed{74\%}$$

e) This process may be an economical process, but it is not an efficient process.

Only

$$\frac{1000 \text{ lb / hr}}{(0.16)(24,600 \text{ lb / hr})} (100) = \boxed{25\%}$$

of the sugar ends up as product.

3.79

Basis: 1 lb fiber through the system and to the drier.

Stock Slurry in

fiber	1 lb
water =	$1 \left(\frac{96}{4} \right) = 24 \text{ lb}$
Total	25 lb

Slurry to Wire

fiber	1 lb
filler	1 lb
water =	$2 \left(\frac{99}{1} \right) = 198 \text{ lb}$
Total	200 lb

Wet Sheet to Drier

fiber	1 lb
filler =	$1 \left(\frac{10}{90} \right) = 0.111 \text{ lb}$
water =	$1.111 \left(\frac{66.7}{33.3} \right) = 2.222 \text{ lb}$

White Water from Wire and Presses

filler =	$1 - 0.111 = 0.889 \text{ lb}$
water =	$198 - 2.222 = 195.8 \text{ lb}$

(continued)

White Water Returned to Headbox

$$\text{water} = 198 - 24 = 174 \text{ lb}$$

$$\text{filler} = \left(\frac{174}{195.8} \right) (0.889) = 0.790 \text{ lb}$$

$$\text{Dry Filler Added} = 0.111 + 0.099 = 0.210 \text{ lb}$$

$$\text{Overall filler retention} = \frac{0.111}{0.210} (100) = \boxed{53\%}$$

$$\text{Filler Retention per pass} = \frac{0.111}{1} (100) = \boxed{11.1\%}$$

White Water Discarded

$$\text{water} = 195.8 - 174 = 21.8 \text{ lb}$$

$$\text{filler} = \frac{21.8}{195.8} (0.889) = 0.099 \text{ lb}$$

3.80

Two subsystems exist, hence 4 component balances can be written. No reaction occurs and the process is assumed to be in the steady state. Steps are omitted here. The balances are

System: Splitter

$$\text{Total: } R = E + P$$

$$\text{Fiber: } 2.34 = x^E + x^P$$

$$\text{Water: } 7452 = 4161 + 3291$$

(a)

System: Stock Chest

$$\text{Total: } P + N = L$$

$$\text{Fiber: } x^P + x^N = 103.26$$

$$\text{Water: } 3291 + 18 = 3309$$

$$\text{Also } N(0.15) = 18$$

$$0.85(N) = x^N = 0.85 \left(\frac{18}{0.15} \right) \quad (b)$$

Overall balances

$$\text{Total: } R + N = E + L$$

$$\text{Fiber: } 2.34 + x^N = x^E + 103.26 \quad (c)$$

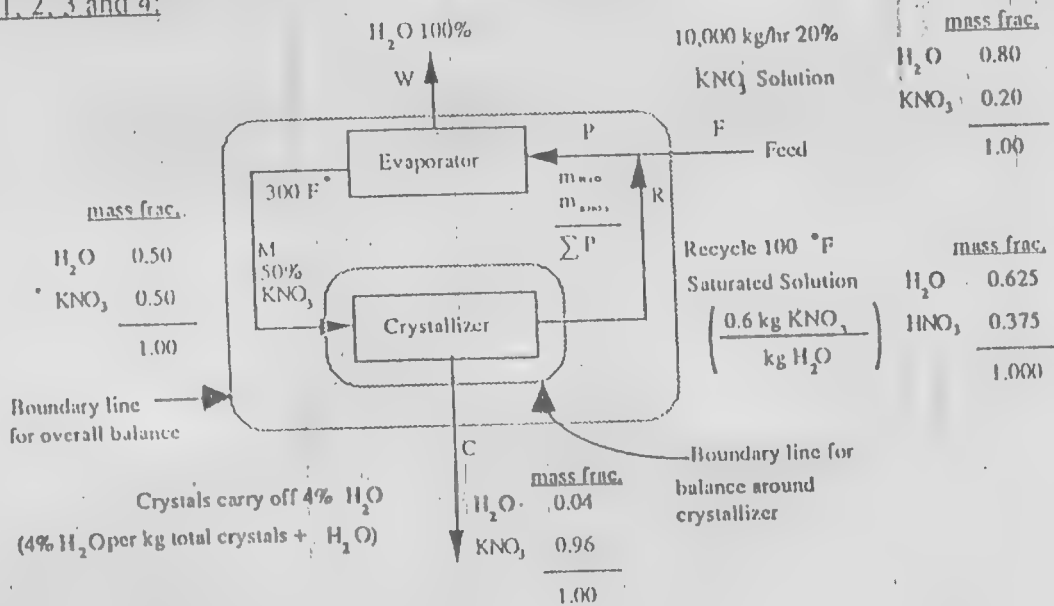
$$\text{Water: } 7452 + 18 = 4161 + 3309$$

Substitute (b) into (c), solve (c) for x^E , and then solve (a) for x^P .

$$\boxed{x^N = 102 \quad x^P = 1.26 \quad x^E = 1.08 \quad \text{all in kg}}$$

3.81

Steps 1, 2, 3 and 4:



Step 5: Basis: 1 hr = 10,000 kg KNO₃ solution

Compute the weight fraction composition of R. On the basis of 1 kg of water, the saturated recycle steam contains (1.0 kg of H₂O + 0.6 kg of KNO₃) = 1.6 kg total. The recycle steam composition is

$$\frac{0.6 \text{ kg KNO}_3}{1 \text{ kg H}_2\text{O}} \cdot \frac{1 \text{ kg H}_2\text{O}}{1.6 \text{ kg solution}} = 0.375 \text{ kg KNO}_3 / \text{kg solution}$$

or 37.5% KNO₃ and 62.5% H₂O (which has been added to the figure).

Analysis of whole problem (6 streams):

Unknowns: W, M, C, R, $m_{H_2O}^P$, $m_{KNO_3}^P$ = 6

Balances: (2 units + 1 mix point) × 2 components = 6

Other compositions are (in %)

	M	E	W	C	R
H ₂ O	50	80	100	4	62.5
KNO ₃	50	20	0	96	37.5

Start with overall balances as substitute for unit balances

Steps 6 and 7: Unknowns: W, C,

Balances: 2 components

(continued)

Overall balance to calculate C: Total: 10,000 = W + C

$$\text{KNO}_3: 10,000 (0.20) = W (0) + C (0.96)$$

$$\frac{10,000 \text{ kg F}}{1 \text{ hr}} \left| \frac{0.20 \text{ kg KNO}_3}{1 \text{ kg F}} \right| \frac{1 \text{ kg crystals}}{0.96 \text{ kg KNO}_3} = 2083 \text{ kg / hr crystals} = C$$

$$W = 10,000 - 2083 = 7917 \text{ kg}$$

To determine the recycle stream R, we need to make a balance that involves the stream R. Either (a) a balance around the evaporator or (b) a balance around the crystallizer will do. The latter is easier since only three rather than four (unknown) streams are involved.

Total balances on crystallizer:

$$M = C + R$$

$$M = 2083 + R \quad \text{①}$$

Component (KNO₃) balance on crystallizer:

$$M \omega_M = C \omega_C + R \omega_R$$

$$0.5M = 0.96C + R (0.375) \quad \text{②}$$

Solving equations ① and ② we obtain

$$0.5 (2083 + R) = 0.375R + 2000$$

$$\boxed{R = 7670 \text{ kg/hr}}$$

3.82

Basis: 1000 lb/hr sea water

$$\text{Overall mass balance: } B + D = 1000 \quad (1)$$

$$\text{Overall salt balance: } 0.0525B + 5.0 \times 10^{-4} D = 31 \quad (2)$$

$$\text{Mass balance around the junction: } 1000 + R = W \quad (3)$$

where R = brine recycle; W = total soln entering the cell

$$\text{Salt balance around the junction: } 31 + 0.0525 R = 0.04W \quad (4)$$

From (1) & (2):

$$\boxed{B = 586 \text{ lb / hr}}$$

&

$$\boxed{D = 414 \text{ lb / hr}}$$

(continued)

From (2) & (4) :

$$R = 720 \text{ lb/hr}$$

$$\text{Fraction} = \frac{720}{720 + 586} = 0.551$$

3.83

Basis : 1 hr $\equiv$ 1L=FOverallBalances: 3 H_2O , Zn, Ni

Unknowns: 3 W, D, P (all in L)

$$\text{Zn: } 100(1) + 0 = \frac{D(1.)}{L} \left| \frac{0.10\text{g}}{\text{L}} \right| + P_0(190.1\text{g/L})$$

$$\text{Ni: } 10(1) + 0 = D(1.00) + P_0(17.02)$$

$$\text{Solve to get } P_0 = 0.525\text{L} \quad D = 1.056\text{L}$$

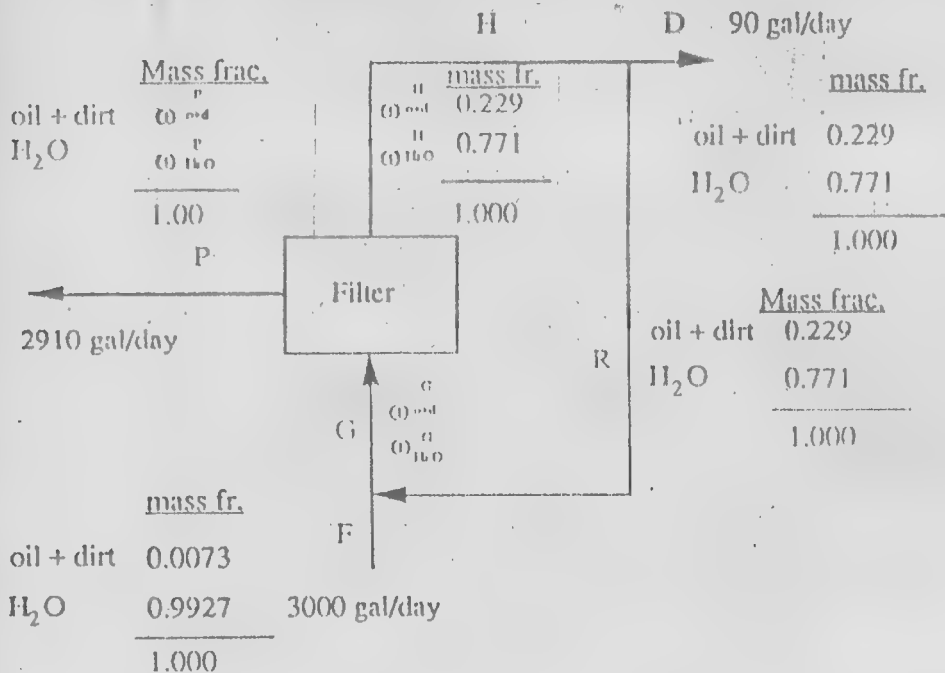
Unit 3Balances: 3 H_2O , Zn, NiUnknowns: 3 W, R_{32} , P_2 (all in L)

$$\text{Zn: } P_2(3.50) + 0 = 0.10(1.056) + R_{32}(4.35)$$

$$\text{Ni: } P_2(2.19) + 0 = 1.00(1.056) + R_{32}(2.36)$$

$$\text{Solve to get } R_{32} = 2.75\text{L/hr}$$

3.84



Unknowns: $H, G, R, \omega_{o+d}^G, \omega_{o+d}^P$ (5) (assuming use $\sum \omega_i = 1$)

Balances: oil + dirt at mix point and filter Plus

$$\omega_{o+d}^H = 20 \omega_{o+d}^G \quad (5)$$

System: Overall

$$\text{In} \quad \text{Out}$$

$$\text{oil + dirt: } 3,000 (0.0073) = 2,910 (\omega_{o+d}^P) + 90 (0.229)$$

$$\omega_{o+d}^P = \frac{21.9 - 20.61}{2,910} = 4.43 \times 10^{-4} \quad (b)$$

System: Mixing Point:

$$\text{oil and dirt: } 3,000 (0.0073) + R (0.229) = G \omega_{o+d}^G$$

$$\text{total: } 3000 + R = G$$

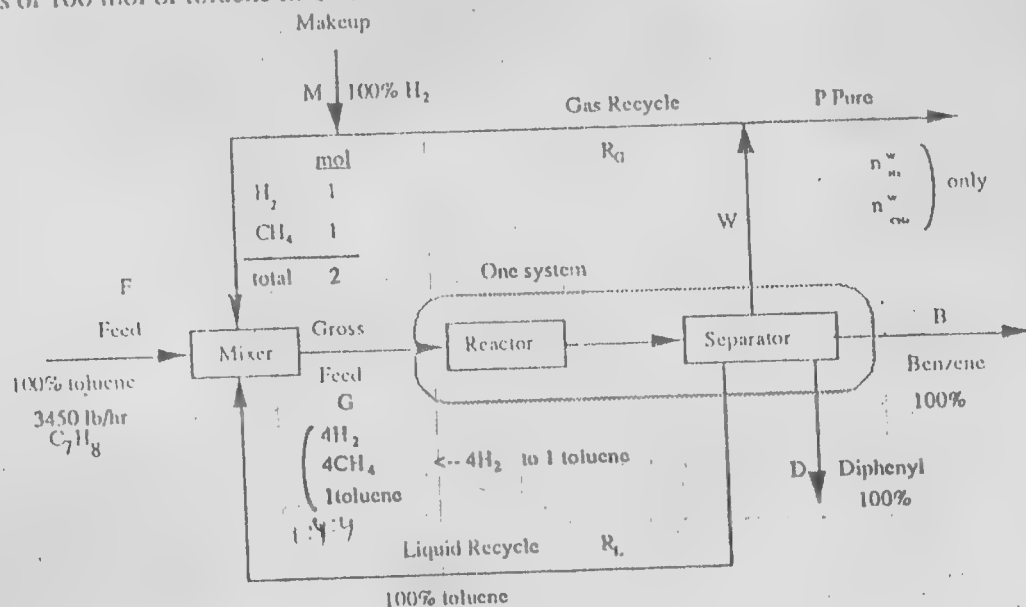
$$\omega_{o+d}^G = \frac{1}{20} (0.229) = 0.01145$$

$$R = 12.45$$

$$R = 60.9 \text{ (along } R \text{)} \quad (a)$$

3.85
A basis of 1 hr requires the listing and solution of many simultaneous equations.

A basis of 100 mol of toluene in G is more convenient



Basis: 100 mol toluene in stream G (gross feed)

System: Reactor plus separator

Compound balances

	In	Out	Gen	Cons.	
(1) toluene:	100	-R _L	+0	100 (.80 + .08)	= 0
(2) H ₂ :	100 (4)	-n _{H₂} ^w	+ 0	-100 (.80 + .08 ($\frac{1}{2}$))	= 0
(3) CH ₄ :	100 (4)	-n _{CH₄} ^w	+ 100 (.80 + .08)	-0	= 0

Solve above for R_L = 12 mol

$$\left. \begin{matrix} n_{H_2}^w = 416 \text{ mol} \\ n_{CH_4}^w = 588 \text{ mol} \end{matrix} \right\} \text{Total} = 1004 \text{ mol}$$

System: Mixer

(Compound balances but no reaction so In = Out)

(continued)

	(F)		(M)		(R _G)		(R _L)		(G) (1)
Toluene:	F (1.0)	+	0	+	0	+	12	=	100
(2) H ₂ :	0	+	+M(1.0)	+	$R_G \left(\frac{416}{1004} \right)$	+	0	=	400
(3) CH ₄ :	0	+	0	+	$R_G \left(\frac{588}{1004} \right)$	+	0	=	400

Solve (3) for $R_G = 683$ mol

Solve (1) for $F = 88$ mol

Change basis to 1 hour

$$\frac{3450 \text{ lb mol}}{92 \text{ lb}} \left| \frac{1 \text{ lb mol}}{92 \text{ lb}} \right| = 37.5 \text{ lb mol of toluene in F}$$

$$\frac{100 \text{ lb mol tol in G}}{88 \text{ lb mol F}} \left| \frac{37.1 \text{ lb mol F}}{1 \text{ hr}} \right| \left| \frac{12 \text{ lb mol R}_L}{100 \text{ lb mol tol in G}} \right| = 5.06 \text{ lb mol R}_L / \text{hr}$$

$$\frac{100}{88} \left| \frac{37.1}{1} \right| \left| \frac{683 \text{ lb mol R}_G}{100 \text{ lb mol tol in G}} \right| = 288 \text{ lb mol R}_G / \text{hr}$$

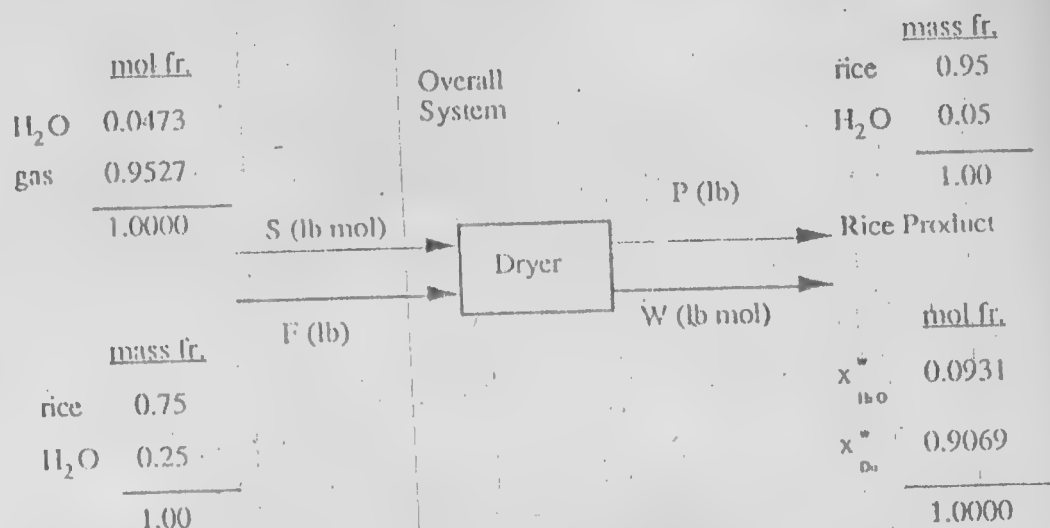
If $F = 37.1$ lb mol, toluene is the basis. You have to make the same balances as above plus benzene and diphenyl balances on the reactor plus separator because F is a known but G becomes an unknown.

The unknowns would be

$$G, R_L, R_G, D, B, M, n_{H_2}^P, n_{CH_4}^P$$

Only 2 elemental balances can be made (overall) so that they could be substituted for some of the compound balances

3.86



Steps 1, 2, 3 and 4: In the diagram use mol and mass percent for compositions and mol and mass for flow as specified.

Step 5: Basis $P = 100 \text{ lb}$

Step 6: Unknowns: F, S, W

Step 7: Can make total and 3 component balances: rice, H₂O, dry gas (G)

Steps 8 and 9:

lb	Rice:	$F(0.75) = P(0.95) = 100(0.95)$
lb mol	Dry gas:	$S(0.9527) = W(0.9069)$
lb mol H ₂ O	H ₂ O:	$S(0.0473) + \frac{F(0.25)}{18.02} = W(0.0931) + \frac{P(0.05)}{18.02}$

$$F = 126.67 \text{ lb}$$

$$S = 29.29 \text{ lb mol}$$

$$W = 30.768 \text{ lb mol}$$

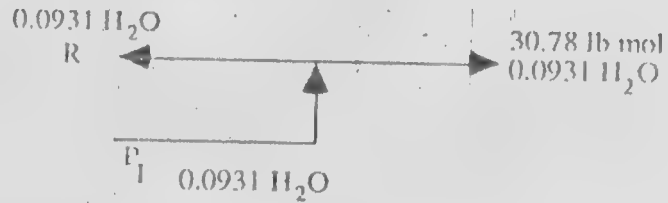


Make balances on the mixing point (easiest)

lb mol gas: $(29.29)(0.9527) + R(0.9069) = F_1 \bar{x}_{DG}^{F_1}$

(continued)

$$\begin{aligned} \text{lb mol H}_2\text{O:} & \quad (29.29)(0.0473) + R (0.0931) = F_1 \times \frac{F_1}{H_2O} \\ \text{lb mol total:} & \quad 29.29 + R = F_1 \\ R & = 3.37 \text{ lb mol / 100 lb P} \end{aligned}$$



or, make balances on separation point

$$\begin{aligned} \text{H}_2\text{O:} & \quad P_1 (0.0931) = R (0.0931) + 30.768 (0.0931) \\ \text{total} & \\ \text{(or G):} & \quad \text{(only 1 independent equation)} \end{aligned}$$

$$0.0473 S + 0.0931 R = F_1 (0.052)$$

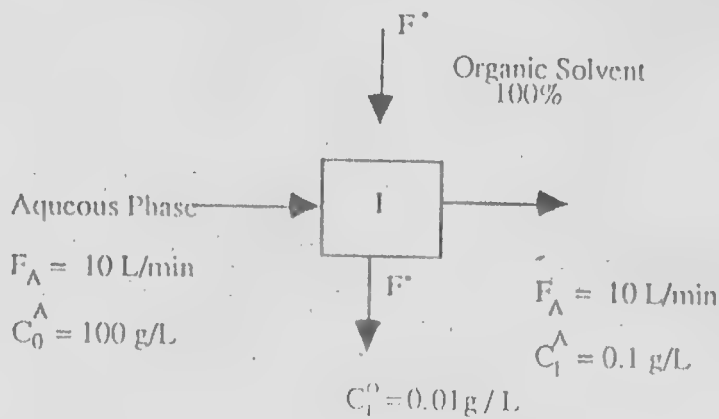
$$29.29 + R = F_1$$

$$1.385 + 0.0931 R = 0.052 (29.29 + R) = 1.523 + 0.052R$$

$$0.041 R = 0.138$$

$$R = 3.37 \text{ lb mol}$$

3.87
A:



Fermentation product balance:

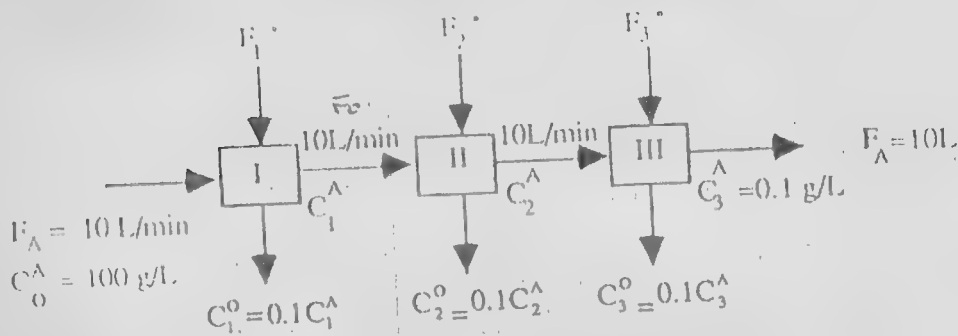
(continued)

$$\frac{C_A}{C_0} = \frac{10}{100} = 0.1$$

$$100 \frac{\text{g}}{\text{L}} \left| \frac{10 \text{ L/min}}{100 \text{ L}} \right| = F^o(0.01) + \frac{10 \text{ L/min}}{100 \text{ L}} \left| \frac{0.1 \text{ g/L}}{100 \text{ L}} \right|$$

$$F^o = \frac{1000 - 1}{0.01} = 99,900 \text{ L/min}$$

B:



Fermentation balance:

Assuming $F_1^o = F_2^o = F_3^o = F^o/3$
input = output

$$\text{I: } \frac{100 \frac{\text{g}}{\text{L}}}{10 \text{ L/min}} = C_1^A \cdot 10 \text{ L/min} + \frac{F^o}{3} \times 0.1 C_1^A \quad (1)$$

$$\text{II: } \frac{C_1^A \frac{\text{g}}{\text{L}}}{10 \text{ L/min}} = C_2^A \cdot 10 \text{ L/min} + \frac{F^o}{3} \times 0.1 C_2^A \quad (2)$$

$$\text{III: } \frac{C_2^A \frac{\text{g}}{\text{L}}}{10 \text{ L/min}} = C_3^A \cdot 10 \text{ L/min} + \frac{F^o}{3} \times 0.1 C_3^A \quad (3)$$

Solving (1), (2) and (3) Simultaneously

$$C_1^A = 10.0 \text{ g/L} \quad C_2^A = 1.0 \text{ g/L} \quad C_3^A = 0.1 \text{ g/L}$$

$$F = 2702 \text{ L/min}$$

(continued)

C:
Fermentation Product Balance:

$$I: \quad \frac{100 \text{ g/L}}{10 \text{ L/min}} + 0.1 C_2^A \cdot F^o = 0.1 C_1^A \cdot F^o + C_{1L}^A \cdot 10$$

$$II: \quad C_1^A \cdot 10 + 0.1(0.1)F^o = 0.1 C_2^A \cdot F^o + C_2^A \cdot 10$$

$$III: \quad C_2^A \cdot 10 + 0 = 0.1(0.1) \cdot F^o + 0.1(10)$$

Solving (1), (2) and (3) Simultaneously

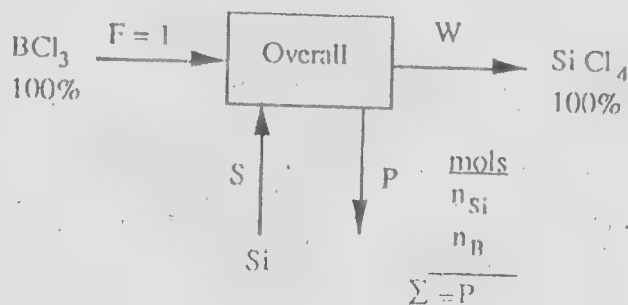
$$C_1^A = 10.36 \text{ g/L}$$

$$C_2^A = 1.06 \text{ g/L}$$

$$C_{1L}^A = 0.10 \text{ g/L}$$

$$F = 960 \text{ L/min}$$

3.88 • Basis : $F = 1 \text{ mol} \equiv 1 \text{ hr}$



Overall balance

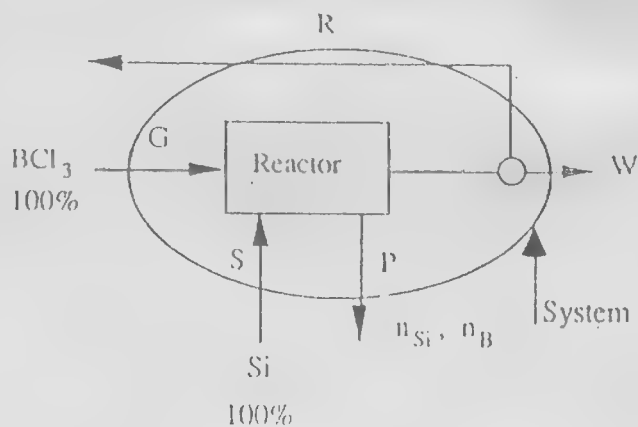
Unknowns: W, n_{Si}, n_B, S (4)

Balances: B, Cl, Si (3)

Reactor plus separator balance

Unknowns: G, R, W, S, n_{Si}, n_B (6)

(continued)



Balances: 4 compounds

Basis: $G = 1 \text{ mol}$ so have 5 unknowns

Mix pt. gives 1 extra balance

Total is now 6 equations.

balances: $F + R + G$

$I + P = G$

Balances on reactor + separator

	In	Out	Gen.	Consum.	
BCl_3	1	$-R (1.0)$	+ 0	$- 1(.87)$	= 0
		$R = 0.13 \text{ mol}$			

Balances on mixing point

$F + R = G$

$F = G - R = 1 - .13 = 0.87 \text{ mol}$

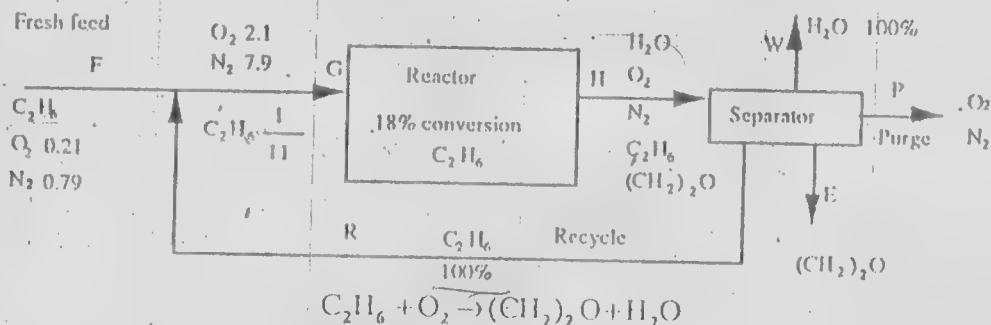
Overall balances

$$\text{Cl: } \begin{array}{c} \text{In} \\ F (3) \end{array} = \begin{array}{c} \text{Out} \\ P(4) \end{array} \quad P = \frac{3}{4} (.87) = 0.65$$

$$\text{ratio} = \frac{0.13}{0.65} = 0.2$$

3.89

Steps 1, 2, and 3:



3 subsystems plus a total system exist. Steady state process.

Step 5:

Basis: $G = 1.00 \text{ mol}$

System: Reactor

(This choice, plus Gas basis, avoids simultaneous equations)

Unknowns: n_i^H (5 of them).

Balances: 5 compound balances

	In	-	Out	+	Generation	-	Consumption	=	0
C_2H_6 :	1	-	$n_{\text{C}_2\text{H}_6}^H$	+	0	-	$1(18)$	=	0
O_2 :	2.1	-	$n_{\text{O}_2}^H$	+	0	-	$1(18)(1.0)$	=	0
N_2 :	7.9	-	$n_{\text{N}_2}^H$	+	0	-	0	=	0
H_2O :	0	-	$n_{\text{H}_2\text{O}}^H$	+	$1(18)(1.00)$	-	0	=	0
$(\text{CH}_2)_2\text{O}$:	0	-	$n_{(\text{CH}_2)_2\text{O}}^H$	+	$1(18)(1.00)$	-	0	=	0

Comp. $n_i \text{ mol}$ mol fr.

C_2H_6	0.82	(a)	0.07
O_2	1.92		0.17
N_2	7.9		0.72
H_2O	0.18		0.02
$(\text{CH}_2)_2\text{O}$	0.18		0.02

$$\begin{aligned} \text{C}_2\text{H}_6 &= 1.00 \\ \text{Air} &= 1.00 \times \frac{21}{100} \\ &= 0.21 \\ &= 7.9 \end{aligned}$$

System: Separator (no reaction)

 $W = 0.18 \text{ mol}$ Purge = $\text{O}_2 + \text{N}_2$ $E = 0.18 \text{ mol}$ $P = 1.92 + 7.9 = 9.82 \text{ mol}$ $R = 0.82 \text{ mol}$

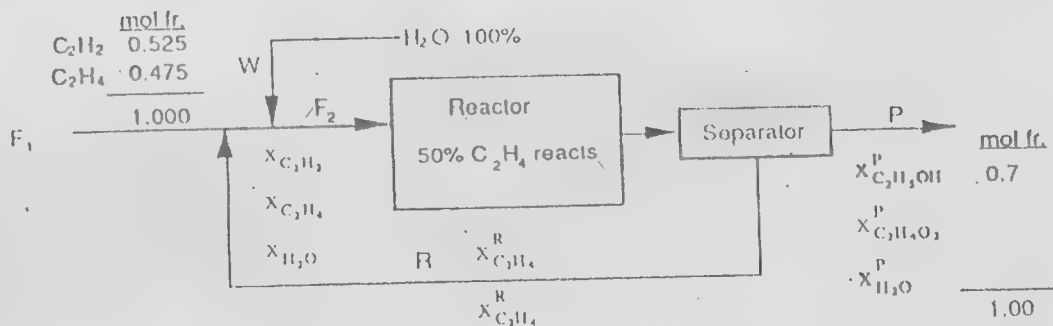
(continued)

System: Mixing Point 3 balances, 3 unknowns (feed elements + ratio O_2/N_2)

$$\left. \begin{array}{l} C_2H_6: n_{C_2H_6}^F + 0.82 = 1.0 \quad n_{C_2H_6}^F = 0.18 \\ O_2: n_{O_2}^F + 0 = 2.1 \quad n_{O_2}^F = 2.1 \\ N_2: n_{N_2}^F + 0 = 7.9 \quad n_{N_2}^F = 7.9 \end{array} \right\} \text{total } 10.18$$

$$\frac{R}{F} = \frac{0.82}{10.18} = 0.081$$

3.90



Basis: $F_1 = 100 \text{ mol}$

$$\text{in } F_2: \frac{C_2H_2}{C_2H_4} = \frac{1.105}{1} = \text{corresponds to } \begin{cases} C_2H_4 & 0.475 \\ C_2H_2 & 0.525 \end{cases}$$

$$\frac{0.4 \text{ kg } H_2O}{1 \text{ kg } C_2H_4} \left| \frac{1 \text{ kg mol } H_2O}{18 \text{ kg } H_2O} \right| \frac{28 \text{ kg } C_2H_4}{1 \text{ kg mol } C_2H_4} \left| \frac{0.475 \text{ mol } C_2H_4}{1 \text{ kg mol } C_2H_4} \right| = 0.2956 \text{ mol } H_2O$$

F_2 mol	
C_2H_2	0.525
C_2H_4	0.475
H_2O	0.2956
Total	1.2956

(continued)

Solutions - Chapter - 3

System: Overall

④

or

③

Unknowns: $W, P, x_{C_2H_4O_2}^P, x_{H_2O}^P$ (assuming use $\sum x_i^P = 1$)

⑥k

Balances: C, H, O

④
plus



$$C: 100[0.525(2) + 0.475(2)] = P[0.70(2) + x_{C_2H_4O_2}^P(2)]$$

$$H: 100[0.525(2) + 0.475(4)] + W(2) = P[0.70(6) + x_{C_2H_4O_2}^P(4) + x_{H_2O}^P(2)]$$

$$O: W(1) = P[0.70(1) + x_{C_2H_4O_2}^P(2) + x_{H_2O}^P(1)]$$

$$0.70 - x_{C_2H_4O_2}^P - x_{H_2O}^P = 1$$

To make eqns. linear, let:

$$\left. \begin{aligned} P x_{C_2H_4O_2}^P &= n_{C_2H_4O_2} \\ P x_{C_2H_4O_2}^P &= n_{C_2H_4O_2} \\ P x_{H_2O}^P &= n_{H_2O} \end{aligned} \right\} \Sigma = P$$

and introduce in above eqns

$$0.70P + n_{C_2H_4O_2} + n_{H_2O} = P$$

$$\left. \begin{aligned} 200 &= 1.40P + n_{C_2H_4O_2} \\ 295.0 &= 4.20P - 2W + 4n_{C_2H_4O_2} + 2n_{H_2O} \\ 0 &= 0.70P - W + 2n_{C_2H_4O_2} + n_{H_2O} \\ n_{C_2H_4O_2} + n_{H_2O} &= 0.30P \end{aligned} \right\}$$

$$\left. \begin{aligned} P &= 105.36 \\ W &= 131.61 \\ n_{C_2H_4O_2} &= 26.25 \\ n_{H_2O} &= 5.36 \end{aligned} \right\} \text{Moles}$$

System mixing point

unknowns: $R, F_2, x_{C_2H_2}^R$

Balances

$$\left. \begin{aligned}
 \text{C}_2\text{H}_2: 100 (0.525) + R x_{\text{C}_2\text{H}_2}^R &= F_2 \left(\frac{0.525}{1.2956} \right) \\
 \text{C}_2\text{H}_4: 100 (0.475) + R x_{\text{C}_2\text{H}_4}^R &= F_2 \left(\frac{0.475}{1.2956} \right) \\
 \text{H}_2\text{O}: 131.61 &= F_2 \left(\frac{0.2956}{1.2956} \right)
 \end{aligned} \right\} \begin{array}{l} \text{Moles} \\ F_2 = 576.84 \\ R = 345.23 \end{array}$$

Total $100 + 131.61 + R = F_2$
 System: reactor plus separator

Balance:

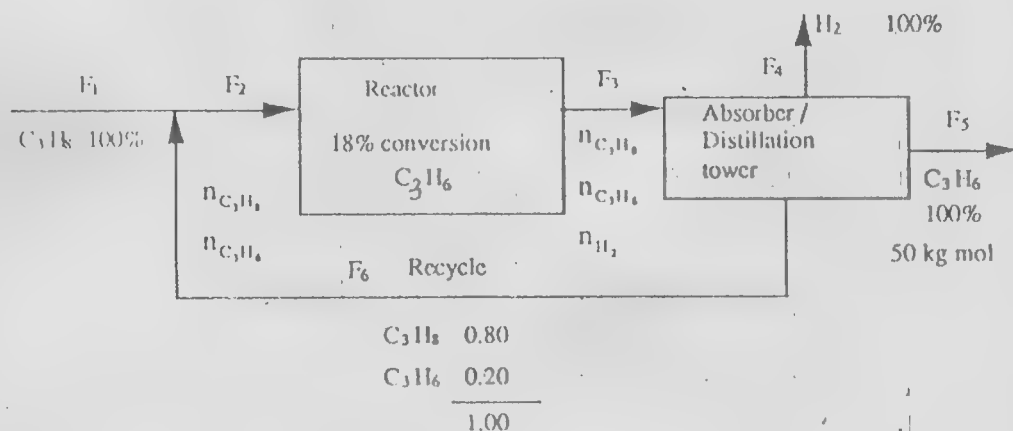
$$\begin{array}{lcl}
 & \text{In} & \text{Out} \quad \text{Consump} \\
 \text{C}_2\text{H}_4: & F_2 x_{\text{C}_2\text{H}_4}^{F_2} - P(0) - R x_{\text{C}_2\text{H}_4}^R - 0.5 (F_2 x_{\text{C}_2\text{H}_4}^{F_2}) & = 0
 \end{array}$$

$$0.6[576.84 (0.475)] = 345.23 (x_{\text{C}_2\text{H}_4}^R)$$

$$x \approx 0.475 \quad x_{\text{C}_2\text{H}_2}^R = 0.525$$

$$\frac{R}{F_1} = \frac{345.23}{100.00} = 3.45$$

3.91

Basis: 1 hr = 50 kg mol F_5

(continued)

Unknowns:

$$F_1, F_4, F_6, n_{C_3H_8}^{F_2}, n_{C_3H_6}^{F_2}, n_{C_3H_8}^{F_1}, n_{C_3H_6}^{F_1}, n_{H_2}^{F_2} \quad (8)$$

Balances:

Mixing Point:	C_3H_8, C_3H_6	} (8)
Reactor:	C_3H_8, C_3H_6, H_2	
Abs./Distil.:	C_3H_8, C_3H_6, H_2	

Use overall balances as substitute for some of the above

Overall balances (atoms because of reaction)

(In)	(Out)	
C: $F_1(3) = F_3(3)$		$F_1 = 50 \text{ kg mol}$
H: $F_1(8) = F_4(2) + F_5(6)$		
$8(50) = 2F_4 + 50(6)$		$F_4 = 50 \text{ kg mol}$

Mixing point balances:

(In)	(Out)
$C_3H_8: F_1(1.0) + F_6(0.8) = n_{C_3H_8}^{F_2} = 50 + 0.8F_6$	
$C_3H_6: F_1(0) + F_6(0.2) = n_{C_3H_6}^{F_2} = 0.2F_6$	

Reactor plus absorber/distillation balances

	In	Out	Generated	Consumed
$C_3H_8:$	$n_{C_3H_8}^{F_2}$	$F_6(0.80)$ (recycle)	+	$0.4 n_{C_3H_8}^{F_2}$
				$= 0$
				$(50 + 0.8F_6) - 0.80 F_6 - 0.4 (50 + 0.8 F_6) = 0$
				$F_6 = 93.75 \text{ kg mol}$
				$n_{C_3H_8}^{F_2} = 75 + 50 = 125 \text{ kgmol}$
$C_3H_6:$	$n_{C_3H_6}^{F_2}$	$F_6(0.20) - 50 + 0.40 (50 + 0.8F_6)$	-	0
				$= 0$
				$n_{C_3H_6}^{F_2} = 18.75 \text{ kg mol}$

Note: since $F_2 = F_1 + F_6 = 50 + 93.75 = 143.75 \text{ kg mol}$ (easier calculated this way)

$$n_{C_3H_6}^{F_2} = 0.2 F_6 = 18.75 \text{ kg mol}$$

(continued)

$$\dot{F}_2 = 18.75 + 125 = 143.75 \text{ kg mol}$$

Omit H_2 balance (Use C_3H_6)

Absorption/distillation tower

$$\text{C}_3\text{H}_6: \quad n_{\text{C}_3\text{H}_6}^{\text{F}_3} = \dot{F}_5 = 50 \text{ kg mol}$$

$$\text{H}_2: \quad n_{\text{H}_2}^{\text{F}_4} = \dot{F}_4 = 50 \text{ kg mol}$$

$$\text{total:} \quad \dot{F}_3 = \dot{F}_4 + \dot{F}_5 + \dot{F}_6 = 50 + 50 + 93.75 = 193.75 \text{ kg mol}$$

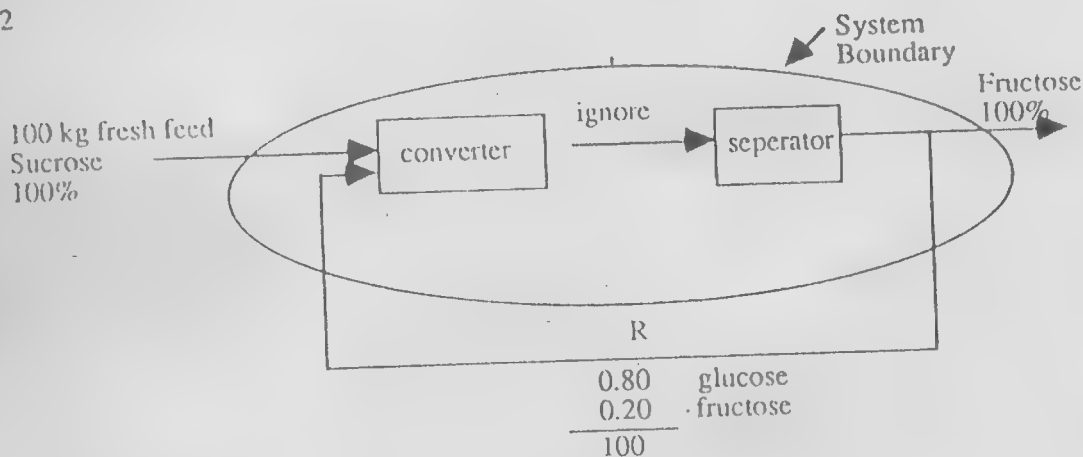
$$n_{\text{C}_3\text{H}_6}^{\text{F}_3} = 193.75 - 100 = 93.75 = \dot{F}_6$$

Summary (all kg mol):

(a)	$\dot{F}_1 = 50$	$\dot{F}_4 = 50$
	$\dot{F}_2 = 143.75$	$\dot{F}_5 = 50$
	$\dot{F}_3 = 193.75$	$\dot{F}_6 = 93.75$

(b) 100% (no. C_3H_6 exists)

3.92



This is a steady state problem with reaction and recycle.

Step 1, 2, 3, and 4:

This is a steady state problem. The balance will be in mass since composition are given as mass fractions.

Step 5:

Basis: 100 kg fresh feed

(continued)

Step 6:

Unknowns are the flow and compositions of the reactor gross product, the separator and R. We only want R so we will use as the system the reactor plus the separator.

Step 7:

Use a glucose balance with 60% conversion of glucose to fructose.

Steps 8 and 9:

In	Out	Generated	Consumed	Accumulation
$(100 + 0.80R)$	$-0.80R$	$+0.0$	$-(100 + 0.80R) \cdot (.60)$	$= 0$
$0.40 (100 + .80R) = .80R$				

$$R = 83.3 \text{ kg}$$

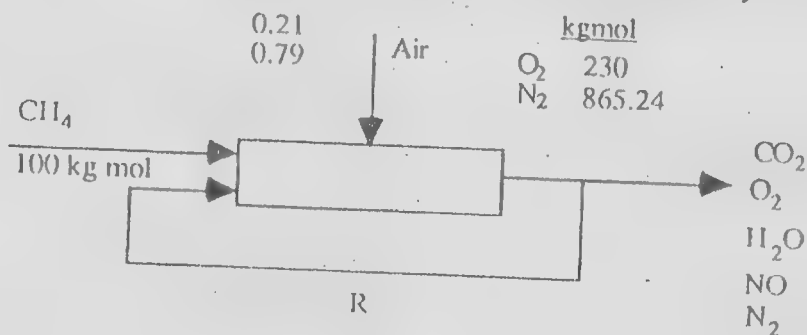
(continued)

3.93

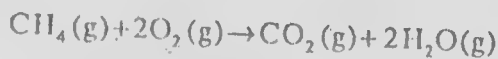
This is steady state process with reaction and recycle.

Steps 1, 2, 3, and 4:

The system is as shown in the diagram with recycle added.



Calculate the moles of each component.



Calculation of the required O_2 and accompanying N_2

$$\text{req'd } \text{O}_2 \quad 100(2) \quad = 200$$

$$\text{xs} \quad 200(0.15) \quad = 30$$

$$\text{Total } \text{O}_2 \quad 230$$

$$\text{N}_2 \text{ in } \left(\frac{230}{.21} \right) = 865.24$$

Calculation of the conversion fraction of N_2 : $\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}$

(continued)

$$\text{Fraction conversion of N}_2 \text{ is } \frac{4.15 \times 10^{-6} \frac{\text{kg mol NO}}{\text{kg mol}}}{865.24 \text{ kg mol in}} \frac{1195.24 \text{ P}}{1} = 0.000573 \text{ or } 5.73 \times 10^{-4}$$

With recycle the overall balances shows that the stack gas composition does not change.

The recycle does reduce the combustion temperature so the fraction conversion of NO is reduced substantially.

3.94

This is a steady state problem with reaction and recycle.

Step 5: Basis: 100 mol F

Steps 1, 2, 3 and 4: Make the overall balances first. $\text{SO}_2 + \frac{1}{2} \text{SO}_3$
(continued)

	kg mol				Use stoichiometry	Calcd. mol	Calcd. mol fr
SO ₂	10.0	F (mol)	Overall Process	P (mol)	SO ₃ 0.95 (10) =	9.50	0.100
O ₂	9.0				SO ₂ 0.05 (10) =	0.50	0.00525
N ₂	81.0				O ₂ 9-4.75 =	4.25	0.0446
					N ₂	81.0	0.850
						<u>95.25</u>	<u>1.000</u>

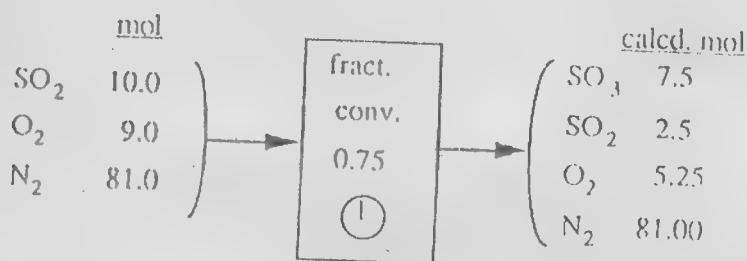
Step 6: The unknowns are the 4 exit compositions.

Steps 7, 8, and 9: We have 3 element balances plus the split of the SO₂ and SO₃ (2 compound balances) or compound balances (SO₃, SO₂, N₂, O₂)

Element S: $10 = 0.95 (10) + 0.05 (10)$

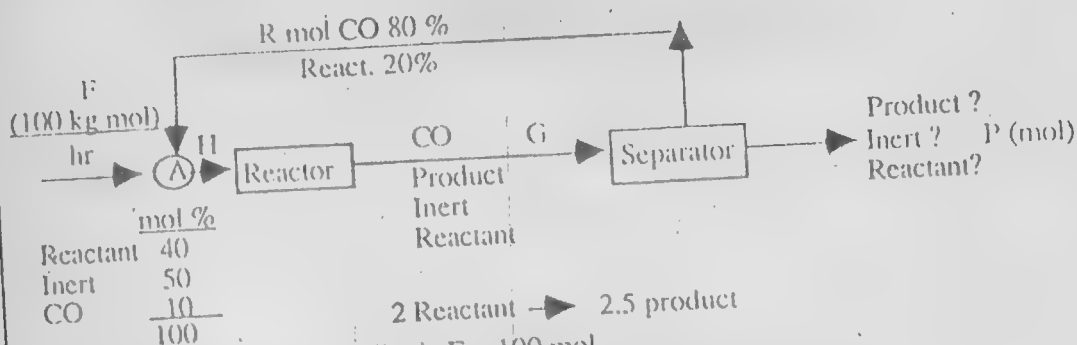
Compound N₂: $81.0 = 81.0$

(continued)



Handwritten notes:
 10.0 / 0.75 = 13.33
 13.33 - 10.0 = 3.33
 3.33 * 0.25 = 0.83
 0.83 + 2.5 = 3.33
 3.33 - 2.5 = 0.83
 0.83 * 0.75 = 0.62
 0.62 + 2.5 = 3.12
 3.12 - 2.5 = 0.62
 0.62 * 0.75 = 0.47
 0.47 + 2.5 = 2.97
 2.97 - 2.5 = 0.47
 0.47 * 0.75 = 0.35
 0.35 + 2.5 = 2.85
 2.85 - 2.5 = 0.35
 0.35 * 0.75 = 0.26
 0.26 + 2.5 = 2.76
 2.76 - 2.5 = 0.26
 0.26 * 0.75 = 0.19
 0.19 + 2.5 = 2.69
 2.69 - 2.5 = 0.19
 0.19 * 0.75 = 0.14
 0.14 + 2.5 = 2.64
 2.64 - 2.5 = 0.14
 0.14 * 0.75 = 0.11
 0.11 + 2.5 = 2.61
 2.61 - 2.5 = 0.11
 0.11 * 0.75 = 0.08
 0.08 + 2.5 = 2.58
 2.58 - 2.5 = 0.08
 0.08 * 0.75 = 0.06
 0.06 + 2.5 = 2.56
 2.56 - 2.5 = 0.06
 0.06 * 0.75 = 0.04
 0.04 + 2.5 = 2.54
 2.54 - 2.5 = 0.04
 0.04 * 0.75 = 0.03
 0.03 + 2.5 = 2.53
 2.53 - 2.5 = 0.03
 0.03 * 0.75 = 0.02
 0.02 + 2.5 = 2.52
 2.52 - 2.5 = 0.02
 0.02 * 0.75 = 0.01
 0.01 + 2.5 = 2.51
 2.51 - 2.5 = 0.01
 0.01 * 0.75 = 0.0075
 0.0075 + 2.5 = 2.5075
 2.5075 - 2.5 = 0.0075
 0.0075 * 0.75 = 0.0056
 0.0056 + 2.5 = 2.5056
 2.5056 - 2.5 = 0.0056
 0.0056 * 0.75 = 0.0042
 0.0042 + 2.5 = 2.5042
 2.5042 - 2.5 = 0.0042
 0.0042 * 0.75 = 0.0031
 0.0031 + 2.5 = 2.5031
 2.5031 - 2.5 = 0.0031
 0.0031 * 0.75 = 0.0023
 0.0023 + 2.5 = 2.5023
 2.5023 - 2.5 = 0.0023
 0.0023 * 0.75 = 0.0017
 0.0017 + 2.5 = 2.5017
 2.5017 - 2.5 = 0.0017
 0.0017 * 0.75 = 0.0013
 0.0013 + 2.5 = 2.5013
 2.5013 - 2.5 = 0.0013
 0.0013 * 0.75 = 0.001
 0.001 + 2.5 = 2.501
 2.501 - 2.5 = 0.001
 0.001 * 0.75 = 0.00075
 0.00075 + 2.5 = 2.50075
 2.50075 - 2.5 = 0.00075
 0.00075 * 0.75 = 0.00056
 0.00056 + 2.5 = 2.50056
 2.50056 - 2.5 = 0.00056
 0.00056 * 0.75 = 0.00042
 0.00042 + 2.5 = 2.50042
 2.50042 - 2.5 = 0.00042
 0.00042 * 0.75 = 0.00031
 0.00031 + 2.5 = 2.50031
 2.50031 - 2.5 = 0.00031
 0.00031 * 0.75 = 0.00023
 0.00023 + 2.5 = 2.50023
 2.50023 - 2.5 = 0.00023
 0.00023 * 0.75 = 0.00017
 0.00017 + 2.5 = 2.50017
 2.50017 - 2.5 = 0.00017
 0.00017 * 0.75 = 0.00013
 0.00013 + 2.5 = 2.50013
 2.50013 - 2.5 = 0.00013
 0.00013 * 0.75 = 0.0001
 0.0001 + 2.5 = 2.5001
 2.5001 - 2.5 = 0.0001
 0.0001 * 0.75 = 7.5e-5
 7.5e-5 + 2.5 = 2.500075
 2.500075 - 2.5 = 7.5e-5
 7.5e-5 * 0.75 = 5.6e-5
 5.6e-5 + 2.5 = 2.500056
 2.500056 - 2.5 = 5.6e-5
 5.6e-5 * 0.75 = 4.2e-5
 4.2e-5 + 2.5 = 2.500042
 2.500042 - 2.5 = 4.2e-5
 4.2e-5 * 0.75 = 3.1e-5
 3.1e-5 + 2.5 = 2.500031
 2.500031 - 2.5 = 3.1e-5
 3.1e-5 * 0.75 = 2.3e-5
 2.3e-5 + 2.5 = 2.500023
 2.500023 - 2.5 = 2.3e-5
 2.3e-5 * 0.75 = 1.7e-5
 1.7e-5 + 2.5 = 2.500017
 2.500017 - 2.5 = 1.7e-5
 1.7e-5 * 0.75 = 1.3e-5
 1.3e-5 + 2.5 = 2.500013
 2.500013 - 2.5 = 1.3e-5
 1.3e-5 * 0.75 = 1e-5
 1e-5 + 2.5 = 2.50001
 2.50001 - 2.5 = 1e-5
 1e-5 * 0.75 = 7.5e-6
 7.5e-6 + 2.5 = 2.5000075
 2.5000075 - 2.5 = 7.5e-6
 7.5e-6 * 0.75 = 5.6e-6
 5.6e-6 + 2.5 = 2.5000056
 2.5000056 - 2.5 = 5.6e-6
 5.6e-6 * 0.75 = 4.2e-6
 4.2e-6 + 2.5 = 2.5000042
 2.5000042 - 2.5 = 4.2e-6
 4.2e-6 * 0.75 = 3.1e-6
 3.1e-6 + 2.5 = 2.5000031
 2.5000031 - 2.5 = 3.1e-6
 3.1e-6 * 0.75 = 2.3e-6
 2.3e-6 + 2.5 = 2.5000023
 2.5000023 - 2.5 = 2.3e-6
 2.3e-6 * 0.75 = 1.7e-6
 1.7e-6 + 2.5 = 2.5000017
 2.5000017 - 2.5 = 1.7e-6
 1.7e-6 * 0.75 = 1.3e-6
 1.3e-6 + 2.5 = 2.5000013
 2.5000013 - 2.5 = 1.3e-6
 1.3e-6 * 0.75 = 1e-6
 1e-6 + 2.5 = 2.500001
 2.500001 - 2.5 = 1e-6
 1e-6 * 0.75 = 7.5e-7
 7.5e-7 + 2.5 = 2.50000075
 2.50000075 - 2.5 = 7.5e-7
 7.5e-7 * 0.75 = 5.6e-7
 5.6e-7 + 2.5 = 2.50000056
 2.50000056 - 2.5 = 5.6e-7
 5.6e-7 * 0.75 = 4.2e-7
 4.2e-7 + 2.5 = 2.50000042
 2.50000042 - 2.5 = 4.2e-7
 4.2e-7 * 0.75 = 3.1e-7
 3.1e-7 + 2.5 = 2.50000031
 2.50000031 - 2.5 = 3.1e-7
 3.1e-7 * 0.75 = 2.3e-7
 2.3e-7 + 2.5 = 2.50000023
 2.50000023 - 2.5 = 2.3e-7
 2.3e-7 * 0.75 = 1.7e-7
 1.7e-7 + 2.5 = 2.50000017
 2.50000017 - 2.5 = 1.7e-7
 1.7e-7 * 0.75 = 1.3e-7
 1.3e-7 + 2.5 = 2.50000013
 2.50000013 - 2.5 = 1.3e-7
 1.3e-7 * 0.75 = 1e-7
 1e-7 + 2.5 = 2.5000001
 2.5000001 - 2.5 = 1e-7
 1e-7 * 0.75 = 7.5e-8
 7.5e-8 + 2.5 = 2.500000075
 2.500000075 - 2.5 = 7.5e-8
 7.5e-8 * 0.75 = 5.6e-8
 5.6e-8 + 2.5 = 2.500000056
 2.500000056 - 2.5 = 5.6e-8
 5.6e-8 * 0.75 = 4.2e-8
 4.2e-8 + 2.5 = 2.500000042
 2.500000042 - 2.5 = 4.2e-8
 4.2e-8 * 0.75 = 3.1e-8
 3.1e-8 + 2.5 = 2.500000031
 2.500000031 - 2.5 = 3.1e-8
 3.1e-8 * 0.75 = 2.3e-8
 2.3e-8 + 2.5 = 2.500000023
 2.500000023 - 2.5 = 2.3e-8
 2.3e-8 * 0.75 = 1.7e-8
 1.7e-8 + 2.5 = 2.500000017
 2.500000017 - 2.5 = 1.7e-8
 1.7e-8 * 0.75 = 1.3e-8
 1.3e-8 + 2.5 = 2.500000013
 2.500000013 - 2.5 = 1.3e-8
 1.3e-8 * 0.75 = 1e-8
 1e-8 + 2.5 = 2.50000001
 2.50000001 - 2.5 = 1e-8
 1e-8 * 0.75 = 7.5e-9
 7.5e-9 + 2.5 = 2.5000000075
 2.5000000075 - 2.5 = 7.5e-9
 7.5e-9 * 0.75 = 5.6e-9
 5.6e-9 + 2.5 = 2.5000000056
 2.5000000056 - 2.5 = 5.6e-9
 5.6e-9 * 0.75 = 4.2e-9
 4.2e-9 + 2.5 = 2.5000000042
 2.5000000042 - 2.5 = 4.2e-9
 4.2e-9 * 0.75 = 3.1e-9
 3.1e-9 + 2.5 = 2.5000000031
 2.5000000031 - 2.5 = 3.1e-9
 3.1e-9 * 0.75 = 2.3e-9
 2.3e-9 + 2.5 = 2.5000000023
 2.5000000023 - 2.5 = 2.3e-9
 2.3e-9 * 0.75 = 1.7e-9
 1.7e-9 + 2.5 = 2.5000000017
 2.5000000017 - 2.5 = 1.7e-9
 1.7e-9 * 0.75 = 1.3e-9
 1.3e-9 + 2.5 = 2.5000000013
 2.5000000013 - 2.5 = 1.3e-9
 1.3e-9 * 0.75 = 1e-9
 1e-9 + 2.5 = 2.500000001
 2.500000001 - 2.5 = 1e-9
 1e-9 * 0.75 = 7.5e-10
 7.5e-10 + 2.5 = 2.50000000075
 2.50000000075 - 2.5 = 7.5e-10
 7.5e-10 * 0.75 = 5.6e-10
 5.6e-10 + 2.5 = 2.50000000056
 2.50000000056 - 2.5 = 5.6e-10
 5.6e-10 * 0.75 = 4.2e-10
 4.2e-10 + 2.5 = 2.50000000042
 2.50000000042 - 2.5 = 4.2e-10
 4.2e-10 * 0.75 = 3.1e-10
 3.1e-10 + 2.5 = 2.50000000031
 2.50000000031 - 2.5 = 3.1e-10
 3.1e-10 * 0.75 = 2.3e-10
 2.3e-10 + 2.5 = 2.50000000023
 2.50000000023 - 2.5 = 2.3e-10
 2.3e-10 * 0.75 = 1.7e-10
 1.7e-10 + 2.5 = 2.50000000017
 2.50000000017 - 2.5 = 1.7e-10
 1.7e-10 * 0.75 = 1.3e-10
 1.3e-10 + 2.5 = 2.50000000013
 2.50000000013 - 2.5 = 1.3e-10
 1.3e-10 * 0.75 = 1e-10
 1e-10 + 2.5 = 2.5000000001
 2.5000000001 - 2.5 = 1e-10
 1e-10 * 0.75 = 7.5e-11
 7.5e-11 + 2.5 = 2.500000000075
 2.500000000075 - 2.5 = 7.5e-11
 7.5e-11 * 0.75 = 5.6e-11
 5.6e-11 + 2.5 = 2.500000000056
 2.500000000056 - 2.5 = 5.6e-11
 5.6e-11 * 0.75 = 4.2e-11
 4.2e-11 + 2.5 = 2.500000000042
 2.500000000042 - 2.5 = 4.2e-11
 4.2e-11 * 0.75 = 3.1e-11
 3.1e-11 + 2.5 = 2.500000000031
 2.500000000031 - 2.5 = 3.1e-11
 3.1e-11 * 0.75 = 2.3e-11
 2.3e-11 + 2.5 = 2.500000000023
 2.500000000023 - 2.5 = 2.3e-11
 2.3e-11 * 0.75 = 1.7e-11
 1.7e-11 + 2.5 = 2.500000000017
 2.500000000017 - 2.5 = 1.7e-11
 1.7e-11 * 0.75 = 1.3e-11
 1.3e-11 + 2.5 = 2.500000000013
 2.500000000013 - 2.5 = 1.3e-11
 1.3e-11 * 0.75 = 1e-11
 1e-11 + 2.5 = 2.50000000001
 2.50000000001 - 2.5 = 1e-11
 1e-11 * 0.75 = 7.5e-12
 7.5e-12 + 2.5 = 2.5000000000075
 2.5000000000075 - 2.5 = 7.5e-12
 7.5e-12 * 0.75 = 5.6e-12
 5.6e-12 + 2.5 = 2.5000000000056
 2.5000000000056 - 2.5 = 5.6e-12
 5.6e-12 * 0.75 = 4.2e-12
 4.2e-12 + 2.5 = 2.5000000000042
 2.5000000000042 - 2.5 = 4.2e-12
 4.2e-12 * 0.75 = 3.1e-12
 3.1e-12 + 2.5 = 2.5000000000031
 2.5000000000031 - 2.5 = 3.1e-12
 3.1e-12 * 0.75 = 2.3e-12
 2.3e-12 + 2.5 = 2.5000000000023
 2.5000000000023 - 2.5 = 2.3e-12
 2.3e-12 * 0.75 = 1.7e-12
 1.7e-12 + 2.5 = 2.5000000000017
 2.5000000000017 - 2.5 = 1.7e-12
 1.7e-12 * 0.75 = 1.3e-12
 1.3e-12 + 2.5 = 2.5000000000013
 2.5000000000013 - 2.5 = 1.3e-12
 1.3e-12 * 0.75 = 1e-12
 1e-12 + 2.5 = 2.500000000001
 2.500000000001 - 2.5 = 1e-12
 1e-12 * 0.75 = 7.5e-13
 7.5e-13 + 2.5 = 2.50000000000075
 2.50000000000075 - 2.5 = 7.5e-13
 7.5e-13 * 0.75 = 5.6e-13
 5.6e-13 + 2.5 = 2.50000000000056
 2.50000000000056 - 2.5 = 5.6e-13
 5.6e-13 * 0.75 = 4.2e-13
 4.2e-13 + 2.5 = 2.50000000000042
 2.50000000000042 - 2.5 = 4.2e-13
 4.2e-13 * 0.75 = 3.1e-13
 3.1e-13 + 2.5 = 2.50000000000031
 2.50000000000031 - 2.5 = 3.1e-13
 3.1e-13 * 0.75 = 2.3e-13
 2.3e-13 + 2.5 = 2.50000000000023
 2.50000000000023 - 2.5 = 2.3e-13
 2.3e-13 * 0.75 = 1.7e-13
 1.7e-13 + 2.5 = 2.50000000000017
 2.50000000000017 - 2.5 = 1.7e-13
 1.7e-13 * 0.75 = 1.3e-13
 1.3e-13 + 2.5 = 2.50000000000013
 2.50000000000013 - 2.5 = 1.3e-13
 1.3e-13 * 0.75 = 1e-13
 1e-13 + 2.5 = 2.5000000000001
 2.5000000000001 - 2.5 = 1e-13
 1e-13 * 0.75 = 7.5e-14
 7.5e-14 + 2.5 = 2.500000000000075
 2.500000000000075 - 2.5 = 7.5e-14
 7.5e-14 * 0.75 = 5.6e-14
 5.6e-14 + 2.5 = 2.500000000000056
 2.500000000000056 - 2.5 = 5.6e-14
 5.6e-14 * 0.75 = 4.2e-14
 4.2e-14 + 2.5 = 2.500000000000042
 2.500000000000042 - 2.5 = 4.2e-14
 4.2e-14 * 0.75 = 3.1e-14
 3.1e-14 + 2.5 = 2.500000000000031
 2.500000000000031 - 2.5 = 3.1e-14
 3.1e-14 * 0.75 = 2.3e-14
 2.3e-14 + 2.5 = 2.500000000000023
 2.500000000000023 - 2.5 = 2.3e-14
 2.3e-14 * 0.75 = 1.7e-14
 1.7e-14 + 2.5 = 2.500000000000017
 2.500000000000017 - 2.5 = 1.7e-14
 1.7e-14 * 0.75 = 1.3e-14
 1.3e-14 + 2.5 = 2.500000000000013
 2.500000000000013 - 2.5 = 1.3e-14
 1.3e-14 * 0.75 = 1e-14
 1e-14 + 2.5 = 2.50000000000001
 2.50000000000001 - 2.5 = 1e-14
 1e-14 * 0.75 = 7.5e-15
 7.5e-15 + 2.5 = 2.5000000000000075
 2.5000000000000075 - 2.5 = 7.5e-15
 7.5e-15 * 0.75 = 5.6e-15
 5.6e-15 + 2.5 = 2.5000000000000056
 2.5000000000000056 - 2.5 = 5.6e-15
 5.6e-15 * 0.75 = 4.2e-15
 4.2e-15 + 2.5 = 2.5000000000000042
 2.5000000000000042 - 2.5 = 4.2e-15
 4.2e-15 * 0.75 = 3.1e-15
 3.1e-15 + 2.5 = 2.5000000000000031
 2.5000000000000031 - 2.5 = 3.1e-15
 3.1e-15 * 0.75 = 2.3e-15
 2.3e-15 + 2.5 = 2.5000000000000023
 2.5000000000000023 - 2.5 = 2.3e-15
 2.3e-15 * 0.75 = 1.7e-15
 1.7e-15 + 2.5 = 2.5000000000000017
 2.5000000000000017 - 2.5 = 1.7e-15
 1.7e-15 * 0.75 = 1.3e-15
 1.3e-15 + 2.5 = 2.5000000000000013
 2.5000000000000013 - 2.5 = 1.3e-15
 1.3e-15 * 0.75 = 1e-15
 1e-15 + 2.5 = 2.500000000000001
 2.500000000000001 - 2.5 = 1e-15
 1e-15 * 0.75 = 7.5e-16
 7.5e-16 + 2.5 = 2.50000000000000075
 2.50000000000000075 - 2.5 = 7.5e-16
 7.5e-16 * 0.75 = 5.6e-16
 5.6e-16 + 2.5 = 2.50000000000000056
 2.50000000000000056 - 2.5 = 5.6e-16
 5.6e-16 * 0.75 = 4.2e-16
 4.2e-16 + 2.5 = 2.50000000000000042
 2.50000000000000042 - 2.5 = 4.2e-16
 4.2e-16 * 0.75 = 3.1e-16
 3.1e-16 + 2.5 = 2.50000000000000031
 2.50000000000000031 - 2.5 = 3.1e-16
 3.1e-16 * 0.75 = 2.3e-16
 2.3e-16 + 2.5 = 2.50000000000000023
 2.50000000000000023 - 2.5 = 2.3e-16
 2.3e-16 * 0.75 = 1.7e-16
 1.7e-16 + 2.5 = 2.50000000000000017
 2.50000000000000017 - 2.5 = 1.7e-16
 1.7e-16 * 0.75 = 1.3e-16
 1.3e-16 + 2.5 = 2.50000000000000013
 2.50000000000000013 - 2.5 = 1.3e-16
 1.3e-16 * 0.75 = 1e-16
 1e-16 + 2.5 = 2.5000000000000001
 2.5000000000000001 - 2.5 = 1e-16
 1e-16 * 0.75 = 7.5e-17
 7.5e-17 + 2.5 = 2.500000000000000075
 2.500000000000000075 - 2.5 = 7.5e-17
 7.5e-17 * 0.75 = 5.6e-17
 5.6e-17 + 2.5 = 2.500000000000000056
 2.500000000000000056 - 2.5 = 5.6e-17
 5.6e-17 * 0.75 = 4.2e-17
 4.2e-17 + 2.5 = 2.500000000000000042
 2.500000000000000042 - 2.5 = 4.2e-17
 4.2e-17 * 0.75 = 3.1e-17
 3.1e-17 + 2.5 = 2.500000000000000031
 2.500000000000000031 - 2.5 = 3.1e-17
 3.1e-17 * 0.75 = 2.3e-17
 2.3e-17 + 2.5 = 2.500000000000000023
 2.500000000000000023 - 2.5 = 2.3e-17
 2.3e-17 * 0.75 = 1.7e-17
 1.7e-17 + 2.5 = 2.500000000000000017
 2.500000000000000017 - 2.5 = 1.7e-17
 1.7e-17 * 0.75 = 1.3e-17
 1.3e-17 + 2.5 = 2.500000000000000013
 2.500000000000000013 - 2.5 = 1.3e-17
 1.3e-17 * 0.75 = 1e-17
 1e-17 + 2.5 = 2.50000000000000001
 2.50000000000000001 - 2.5 = 1e-17
 1e-17 * 0.75 = 7.5e-18
 7.5e-18 + 2.5 = 2.5000000000000000075
 2.5000000000000000075 - 2.5 = 7.5e-18
 7.5e-18 * 0.75 = 5.6e-18
 5.6e-18 + 2.5 = 2.5000000000000000056
 2.5000000000000000056 - 2.5 = 5.6e-18
 5.6e-18 * 0.75 = 4.2e-18
 4.2e-18 + 2.5 = 2.5000000000000000042
 2.5000000000000000042 - 2.5 = 4.2e-18
 4.2e-18 * 0.75 = 3.1e-18
 3.1e-18 + 2.5 = 2.5000000000000000031
 2.5000000000000000031 - 2.5 = 3.1e-18
 3.1e-18 * 0.75 = 2.3e-18
 2.3e-18 + 2.5 = 2.5000000000000000023
 2.5000000000000000023 - 2.5 = 2.3e-18
 2.3e-18 * 0.75 = 1.7e-18
 1.7e-18 + 2.5 = 2.5000000000000000017
 2.5000000000000000017 - 2.5 = 1.7e-18
 1.7e-18 * 0.75 = 1.3e-18
 1.3e-18 + 2.5 = 2.50000

3.95
Steps 1, 2, 3 and 4:



Step 5:

2 Reactant $\rightarrow$ 2.5 product
Basis: F = 100 mol

Step 6:

Omit G and H so unknowns are F, R, P

Step 7:

Balances : 3 units, 3 components so enough independent balances should be available (some balance are redundant).

Steps 8 and 9:

Overall balance (using stoichiometry)

Exit Stream

Inert = 50 mol

Reactant = 40 (.10) = 4 mol

$$(0.90) \frac{40 \text{ mol Reactant}}{100 \text{ F}} \frac{2.5 \text{ mol Product}}{2 \text{ mol Reactant}} = 45 \text{ mol Product in exit stream}$$

The once through Reactant balance for reactor plus separator

The flow out of (A) is $(0.40(100) + 0.20R)$ and is gross feed to reactor. Conversion is 0.73 of this.

$$[40 + R(.20)]0.27 = \text{reactant out of separator} = R(.20) + 4$$

$$10.8 + 0.054R = 4 + 0.2R$$

$$R = 46.6 \text{ mol}$$

$$\frac{R}{P} = \frac{46.6 \text{ mol R}}{45 \text{ mol Product}} = 1.035$$

3.96

Steady state process with reaction

Step 1, 2, 3, and 4: Get the amount of (reqd., excess) HNO_3 in G.

Step 5:

Basis: 1 hr

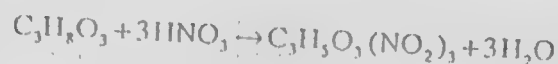
(continued)

Solutions - Chapter - 3

$$\frac{1 \times 10^3 \text{ kg Glycerine}}{92.11 \text{ kg Gly}} \left| \frac{1 \text{ kg mol Gly}}{92.11 \text{ kg Gly}} \right| = 10.86 \text{ lb mol Gly}$$

Step 4:

Glycerine



Required: HNO_3 is $3(10.86) = 32.58 \text{ kg mol}$

Excess: HNO_3 is $32.56(20) = 6.516$
Total: $39.10 \text{ kg mol in G}$

Steps 6 and 7:

System is overall

Unknown are $F, P, m_{\text{H}_2\text{SO}_4}^w$, and $m_{\text{H}_2\text{O}}^w$

($\Sigma m_i = W$)

Equations are: C, H, S, O, N
(continued)

(or you can use stoichiometry and make compound balances)

C: $10.86 = 0.9650 P$

$P = 11.25 \text{ kg mol or } 11.25(227.09)$

$= 2556 \text{ kg}$

(a)

System is the mixing point

Unknowns: $F, m_{\text{H}_2\text{SO}_4}, m_{\text{H}_2\text{O}}, R, G$

(5)

Balances: $\text{H}_2\text{SO}_4, \text{H}_2\text{O}; \text{HNO}_3$ and $m_{\text{H}_2\text{O}} + m_{\text{H}_2\text{SO}_4} + 39.10 = G$

(4)

(a) Glycerine Feed $= \frac{1000}{92.11} = 10.86 \text{ lb mol}$

Nitroglycerine Produced $= \frac{10.86 \text{ lb mol}}{1 \text{ lb mol}} \left| \frac{227.09 \text{ lb}}{1 \text{ lb mol}} \right| = 2465 \text{ lb}$

$0.9650 P = 2465$

$P = 2555 \text{ lb}$

(a)

(b) Mol HNO_3 req'd $= \frac{10.86 \text{ mols Glyc.}}{1 \text{ mol Glyc.}} \left| \frac{3 \text{ mol HNO}_3}{1 \text{ mol Glyc.}} \right|$
 $= 32.58 \text{ mol}$

(continued)

$$\text{Actual HNO}_3 \text{ Req'd} = 1.200 (32.58) = 39.10 \text{ mol}$$

$$\text{HNO}_3 \text{ in R} = 39.10 - 32.58 = 6.52 \text{ mol}$$

$$= 6.52 (63.01) = 411 \text{ lb}$$

$$\text{HNO}_3 \text{ is 70.00\% R, } 0.7000\text{R} = 411$$

$$\boxed{\text{R} = 587 \text{ lb}}$$

(b)

$$(c) \quad \text{HNO}_3 \text{ in G} = 39.10 \text{ mol} = 2464 \text{ lb}$$

$$\text{HNO}_3 \text{ in R} = 411 \text{ lb}$$

$$\text{F} + \text{R} = \text{G}$$

$$\text{HNO}_3 \text{ Balance: } \text{F} + 411 = 2464 \quad \text{F} = 2053 \text{ lb HNO}_3$$

$$\text{F is 43.00\% HNO}_3 \text{ so that } 0.4300 \text{ F} = 2053$$

$$\boxed{\text{F} = 4774 \text{ lb}}$$

(c)

$$(d) \quad \text{H}_2\text{SO}_4 \text{ in F} = 0.5000 (4774) = 2387 \text{ lb}$$

$$= \text{H}_2\text{SO}_4 \text{ in W}$$

$$\text{H}_2\text{O in F} = 0.0700 (4774) = 334 \text{ lb}$$

$$\text{H}_2\text{O Generated by reaction} = 10.86 \text{ Mole Glyc} \times 3$$

$$= (10.86) (3) (18.02) = 587 \text{ lb}$$

$$\text{H}_2\text{O in Stream P} = 0.0350 (2555) = 89 \text{ lb}$$

$$\text{H}_2\text{O in W} = \text{H}_2\text{O in F} + \text{H}_2\text{O generated} - \text{H}_2\text{O in P}$$

$$= 334 + 587 - 89 = 832 \text{ lb}$$

Component	lb	wt%
H ₂ SO ₄	2387	74.15
H ₂ O	<u>832</u>	<u>25.85</u>
	3219	100.00

$$\boxed{\text{Stream W} = 3219 \text{ lb/hr}}$$

$$\text{H}_2\text{SO}_4 = 74.15\%$$

(d)

$$\text{H}_2\text{O} = 25.85\%$$

(continued)

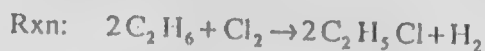
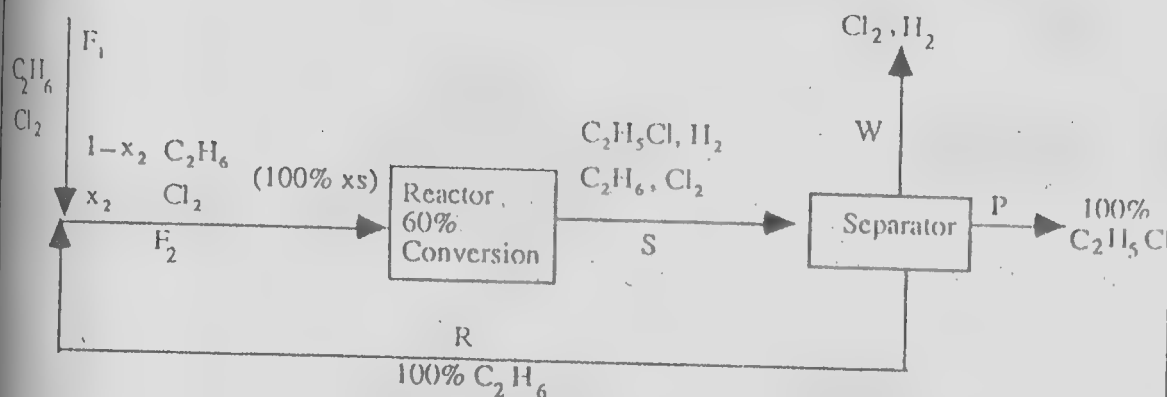
Solutions - Chapter - 3

Do numbers check?

$$\begin{array}{lcl} \text{Glycerine} + F & = & P + W \\ 1000 + 4774 & = & 2555 + 3219 \\ 5774 & = & 5774 \end{array}$$

3.97

Steps 1, 2, 3, and 4



Step 5: Basis: 1 mol C_2H_6 in F_2

Composition of F_2 : Basis: 1 g mol C_2H_6 in F_2

$$x \text{ g mol Cl}_2 - \frac{0.5 \text{ g mol Cl}_2}{1 \text{ g mol C}_2\text{H}_6} \bigg| \frac{1 \text{ g mol C}_2\text{H}_6}{1 \text{ g mol C}_2\text{H}_6}$$

100% excess $\text{Cl}_2 =$

$$\frac{0.5 \text{ g mol Cl}_2}{1 \text{ g mol C}_2\text{H}_6}$$

(100)

$$100 = \frac{x - 0.5}{0.5} (100) \text{ hence } x = \frac{100(0.5)}{100} + 0.5 = \frac{1 \text{ g mol Cl}_2}{1 \text{ g mol C}_2\text{H}_6}$$

$$\text{F}_2 = 1 \text{ g mol C}_2\text{H}_6 + 1 \text{ g mol Cl}_2 = 2 \text{ g mol}$$

Steps 6 and 7:

Unknowns:

(continued)

Overall			At mixer		At reactor + sep			
<u>F₁</u>	<u>W</u>	<u>P</u>	<u>F₁</u>	<u>R</u>	<u>W</u>	<u>P</u>	<u>R</u>	
C ₂ H ₆	Cl ₂	P	C ₂ H ₆		Cl ₂			
Cl ₂	H ₂		Cl ₂		H ₂			

Balances:

Overall			At mixer		At reactor + sep.			
C			C ₂ H ₆		C ₂ H ₆			
H			Cl ₂		Cl ₂			
Cl					Cl ₂ H ₆			
					H ₂			
					inc. rxn bal.			

Incomplete rxn C₂H₆ bal. at reactor plus separator

$$\frac{F_2 \text{ g mol reactor feed}}{\text{g mol reactor feed}} \left| \frac{0.5 \text{ g mol C}_2\text{H}_6}{\text{g mol reactor feed}} \right| \left| \frac{0.4 \text{ g mol unreacted C}_2\text{H}_6}{\text{g mol C}_2\text{H}_6} \right| = R \text{ g mol C}_2\text{H}_6$$

Cl₂ bal. at mixerLet x = mol fraction of Cl₂ in F₁

$$\frac{F_1 \text{ g mol fresh feed}}{\text{g mol fresh feed}} \left| \frac{x \text{ g mol Cl}_2}{\text{g mol fresh feed}} \right| = \frac{F_2 \text{ g mol reactor feed}}{\text{g mol reactor feed}} \left| \frac{0.5 \text{ g mol Cl}_2}{\text{g mol reactor feed}} \right| = 1$$

C₂H₆ bal. at mixer

$$\frac{F_1 \text{ g mol fresh feed}}{\text{g mol fresh feed}} \left| \frac{(1-x) \text{ g mol C}_2\text{H}_6}{\text{g mol fresh feed}} \right| + R \text{ g mol C}_2\text{H}_6 = \frac{F_2 \text{ g mol reactor feed}}{\text{g mol reactor feed}} \left| \frac{0.5 \text{ g mol C}_2\text{H}_6}{\text{g mol reactor feed}} \right|$$

$$F_2 (0.5)(.4) = R \quad \text{hence } R = (2 \text{ mol}) (0.5) (.4) = 0.4 \text{ mol C}_2\text{H}_6$$

$$xF_1 = F_2(0.5) = 1$$

$$F_1(1-x) + 0.4 = 1$$

$$(a) \quad x = \frac{0.5(2 \text{ g mol})}{1.6 \text{ g mol}}$$

$$= 0.625 \text{ mol fraction of Cl}_2 \text{ in } F_1$$

$$F_1 = 1.6$$

$$1 - 0.625 = 0.375 \text{ mol fraction in C}_2\text{H}_6 \text{ in } F_1$$

Overall C₂ balance

(continued)

$$\frac{F_1 \text{ g mol fresh feed}}{\text{g mol fresh feed}} \left| \frac{0.325 \text{ g mol C}_2\text{H}_6 \text{ feed}}{\text{g mol C}_2\text{H}_6 \text{ feed}} \right| \frac{1 \text{ g mol C}_2\text{ feed}}{\text{g mol C}_2\text{H}_6 \text{ feed}} = \frac{P \text{ g mol C}_2\text{H}_5\text{Cl}}{\text{g mol C}_2\text{H}_5\text{Cl}} \left| \frac{1 \text{ g mol C}_2}{\text{g mol C}_2\text{H}_5\text{Cl}} \right|$$

$$\text{g mol C}_2\text{H}_6 \text{ fed} = \frac{F_2 \text{ g mol fresh feed}}{\text{g mol C}_2\text{H}_6 \text{ fresh feed}} \left| \frac{0.325 \text{ g mol C}_2\text{H}_6 \text{ fed}}{\text{g mol C}_2\text{H}_6 \text{ fresh feed}} \right|$$

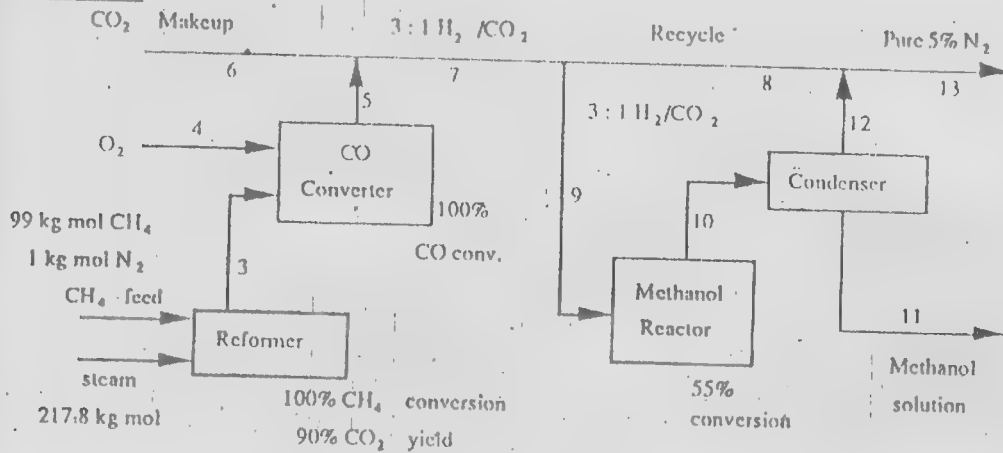
$$= (1.6 \text{ g mol}) (0.325) = 0.6 \text{ g mol C}_2\text{H}_6 \text{ fed}$$

$$F_1 (0.325) = P \quad (1.6) (0.325) = P = 0.6 \text{ g mol C}_2\text{H}_5\text{Cl produced}$$

$$(b) \quad \frac{0.6 \text{ g mol C}_2\text{H}_5\text{Cl produced}}{0.6 \text{ g mol C}_2\text{H}_6 \text{ fed}} = \boxed{1.0}$$

3.98

Step 1, 2, 3 and 4:



Chemical Reactions

- $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow \text{CO}_2 + 4\text{H}_2$ (main reformer rxn)
- $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$ (reformer side rxn)
- $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$ (CO converter rxn)
- $\text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$ (methanol rxn)

CH_4 feed is 1% N_2 or 1 kg mol N_2

steam feed is 10% excess based on reaction (a).

$$99 \text{ kg mol CH}_4 \left(2 \frac{\text{kg mol H}_2\text{O}}{\text{kg mol CH}_4} \right) = 198 \text{ kg mol steam}$$

(continued)

Solutions - Chapter - 3

1.1 (198) = 217.8 kg mol steam

Step 5: Basis: 100 kg mol CH₄ in feed

Steps 6 and 7: Unknowns:

	6-CO ₂ makeup	10-reactor product
3-reformer product	7-3:1 H ₂ /CO ₂	11-Methanol solution
4-O ₂ feed, stoichiometric	8-recycle, H ₂ /CO ₂ =3	12-condenser tops
5-CO conv. products	9-reactor feed, H ₂ /CO ₂ =3	13-purge, 5% N ₂
Balances:	Reformer balance	Condenser balance
	CO conv. balance	purge/recycle balance
	CO ₂ makeup balance	
	Feed/recycle balance	
	Methanol reactor balance	

Steps 8 and 9: Solve balances serially.

Reformer balance gives stream 3

$$\text{CO}_2 = \frac{99 \text{ kg mol CH}_4 \text{ conv.}}{1 \text{ conv.}} \left| \frac{0.9 \text{ conv by (a)}}{1 \text{ conv.}} \right| \frac{1 \text{ kg mol CO}_2}{1 \text{ kg mol CH}_4} = 89.1 \text{ kg mol CO}_2$$

$$\text{CO} = 99(0.1) = 9.9 \text{ kg mol CO}$$

$$\text{H}_2\text{O reacted} = \frac{2 \text{ kg mol H}_2\text{O}}{1 \text{ kg mol CO}_2} \left| \frac{89.1 \text{ kg mol CO}_2}{1 \text{ kg mol CO}_2} \right| + \frac{1 \text{ kg mol H}_2\text{O}}{1 \text{ kg mol CO}} \left| \frac{9.9 \text{ kg mol CO}}{1 \text{ kg mol CO}} \right| = 188.1 \text{ kg mol H}_2\text{O}$$

$$\text{H}_2\text{O remaining} = 217.8 - 188.1 = 29.7 \text{ kg mol H}_2\text{O}$$

$$\text{H}_2 = 4(89.1) + 3(9.9) = 386.1 \text{ kg mol H}_2$$

$$\text{N}_2 = 1 \text{ kg mol}$$

CO conv. balance gives streams 4 & 5:

• (continued)

Stream 4:

$$O_2 = \frac{9.9 \text{ kg mol CO}}{1 \text{ kg mol CO}} \left| \frac{(1/2) \text{ kg mol O}_2}{1 \text{ kg mol CO}} \right| = 4.95 \text{ kg mol O}_2$$

Stream 5:

$$CO_2 = 89.1 + 9.9 = 99 \text{ kg mol CO}_2$$

$$H_2O = 29.7 \text{ kg mol H}_2O$$

$$H_2 = 386.1 \text{ kg mol H}_2$$

$$N_2 = 1 \text{ kg mol N}_2$$

CO₂ makeup gives streams 6 and 7:stream 7 is 3:1 H₂/CO₂

$$CO_2 = 386.1/3 = 128.7 \text{ kg mol CO}_2 \text{ needed}$$

$$\text{Stream 6: } CO_2 = 128.7 - 99 = \boxed{29.7 \text{ kg mol CO}_2}$$

purge/recycle gives stream 13:N₂ is inert species:

$$\text{stream 13} = \frac{1.0 \text{ kg mol N}_2}{0.05 \text{ kg mol N}_2 / \text{kg mol stream 13}} = 20 \text{ kg mol in stream 13}$$

Stream 13:

$$H_2/CO_2 = 3 \quad \text{Let } x = \text{mol frac. of CO}_2 \text{ in stream 13}$$

$$1 = 0.05 + 3x + 1x$$

$$4x = 0.95, \quad x = 0.2375$$

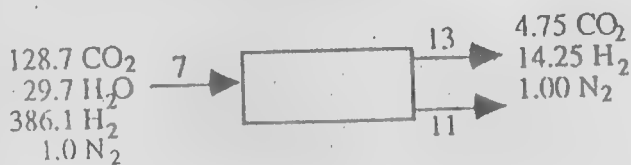
$$N_2 = 1 \text{ kg mol N}_2$$

$$H_2 = 20 (3) (0.2375) = \boxed{14.25 \text{ kg mol H}_2}$$

$$CO_2 = 20 (0.2375) = 4.75 \text{ kg mol CO}_2$$

Special balance gives stream 11:

(continued)



1 rxn occurs

$$\text{CO}_2 \text{ reacted} = 128.7 - 4.75 = 123.95 \text{ kg mol CO}_2 \text{ reacted}$$

$$\text{H}_2 \text{ reacted} = 386.1 - 14.25 = 371.85 \text{ kg mol H}_2 \text{ reacted}$$

$$\text{CH}_3\text{OH produced} = 123.95 \text{ kg mol CH}_3\text{OH}$$

$$\text{H}_2\text{O produced} = 123.95 \text{ kg mol H}_2\text{O}$$

Stream 11:

$$\text{H}_2\text{O} = 29.7 + 123.95 = 153.65 \text{ kg mol H}_2\text{O}$$

$$\text{CH}_3\text{OH} = 123.95 \text{ kg mol CH}_3\text{OH}$$

$$\text{mass stream 11} = 153.65 (18) + 123.95 (32) = \boxed{6732.1 \text{ kg}}$$

$$\text{wt. \% CH}_3\text{OH} = \frac{123.95 (32)}{6732.1} = \boxed{58.9\% \text{ CH}_3\text{OH wt. \%}}$$

Methanol reactor balance for 55% conversion

From special balance, each pass uses 123.95 kg mol CO_2

$$123.95 = 0.55 (\text{CO}_2)_{\text{in}} \text{ so } (\text{CO}_2)_{\text{in}} = 225.36 \text{ kg mol CO}_2$$

$$\text{Stream 8} = \text{stream 9} - \text{stream 7}$$

$$\text{Stream 8: CO}_2 = 225.36 - 128.7 = 95.66$$

$$\text{So } \frac{\text{recycle}}{\text{purge}} = \frac{95.66}{4.75} = \boxed{20.35}$$

4.1 Area of earth's surface = 196,400,000 sq miles from dictionary. $D = 7918$ mi

$$1.964 \times 10^8 \text{ mi}^2 \left| \frac{(5280 \text{ ft})^2}{1 \text{ mi}^2} \right| \left| \frac{(30.48 \text{ cm})^2}{1 \text{ ft}^2} \right| = 5.087 \times 10^{18} \text{ cm}^2 \text{ surface area}$$

$$n = \frac{pV}{RT} = \frac{8.1 \times 10^{18} \text{ molecules}}{6.02 \times 10^{23} \frac{\text{molecules}}{\text{g mol}}} = \frac{1.35 \times 10^{-5} \text{ g mol O}_3}{\text{above each cm}^2 \text{ of Earth's surface}}$$

at STP: $T = 25^\circ\text{C}$

$p = 1.0 \text{ atm}$

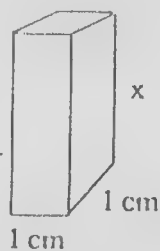
$$V = \frac{nRT}{p} = \frac{1.35 \times 10^{-5} \text{ g mol O}_3}{1.0 \text{ atm}} \left| \frac{25^\circ\text{C} + 273\text{K}}{82.06 \text{ cm}^3 \text{ atm}} \right| \frac{\text{g mol K}}{\text{g mol K}} =$$

0.330 cm^3
per cm^2 of
Earth's surface

$$V = x(1 \text{ cm})(1 \text{ cm}) = 0.330 \text{ cm}^3$$

$$\boxed{x = 0.330 \text{ cm}}$$

$$\frac{0.330 \text{ cm}^3}{1 \text{ cm}^3} \left| \frac{1 \text{ mL}}{1 \text{ cm}^3} \right| \left| \frac{1 \text{ L}}{1000 \text{ mL}} \right| = \boxed{3.30 \times 10^{-4} \text{ L}}$$



4.2 a) $Q = v A$

$$Q = \frac{11.3 \text{ ft}}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left| \frac{(18.0 \text{ in})^2}{(12 \text{ in})^2} \right| \pi = 2.875 \times 10^5 \frac{\text{ft}^3}{\text{hr}}$$

$$\text{In } 1.0 \text{ hr } \boxed{2.875 \times 10^5 \text{ ft}^3}$$

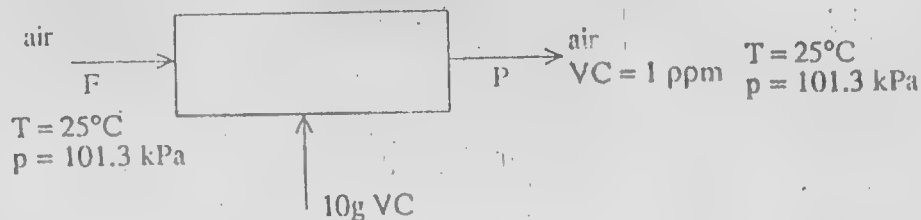
b) $m = \rho v s$

$$m = 0.0796 \frac{\text{lb}_m}{\text{ft}^3} \left| \frac{11.3 \text{ ft}}{\text{s}} \right| \left| \frac{\pi (18.0)^2 \text{ in}^2}{(12 \text{ in})^2} \right| \frac{1 \text{ ft}^2}{\text{ft}^2} = 6.358 \frac{\text{lb}_m}{\text{s}}$$

(continued)

$$\text{In 1 day: } \frac{6.358 \text{ lb}_m}{s} \left| \frac{3600s}{1 \text{ hr}} \right| \frac{24 \text{ hr}}{1} = \boxed{5.49 \times 10^5 \text{ lb}_m}$$

4.3 Basis: 1 min = 10 g VC



Apply $pV = nRT$ to get the volume of VC at SC and then use the mole fraction information to get the volume of air (the addition of VC to air has negligible effect on the volume)

MW VC = 78

$$V_{VC} = \frac{n_{VC}RT}{p} = \frac{0.0101 \text{ kg VC} \left| \frac{1 \text{ kg mol VC}}{78 \text{ kg VC}} \right| 8.314 \text{ (kPa)}(\text{m}^3)}{101.3 \text{ kPa}} \frac{298 \text{ K}}{(\text{kg mol})(\text{K})}$$

$$= 3.01 \times 10^{-3} \text{ m}^3 \text{ VC at SC}$$

Volume fraction is the same as mole fraction here.

$$\frac{3.01 \times 10^{-3} \text{ m}^3 \text{ VC at SC} \left| \frac{10^6 \text{ m}^3 \text{ air}}{1 \text{ m}^3 \text{ VC}} \right|}{(1.06 \times 10^6) \text{ ft}^3/\text{min}} = \boxed{3.01 \times 10^3 \text{ m}^3/\text{min}} \text{ an absurd number!}$$

If a hood is used:

$$\text{area} = \frac{(30)(25) \text{ in}^2 \left| \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right| \frac{100 \text{ ft}}{s} \left(\frac{0.3048 \text{ m}}{1 \text{ ft}} \right)^3 \times \frac{60s}{\text{min}}}$$

$$= \boxed{882 \text{ m}^3/\text{min}} \text{ a smaller amount of air.}$$

Besides inconvenience, the discharge concentration from the hood vent may be unacceptable.

4.4

Basis: 1 L gas at 780 mm Hg and T

$$\frac{1 \text{ L}}{760 \text{ mm Hg}} \times \frac{780 \text{ mm Hg}}{1} = \boxed{1.026 \text{ L}}$$

4.5

$$(pV)_1 = (pV)_2$$

$$1 \times 1 = p \times 1.2$$

$$p = \frac{1}{1.2} = 0.83 \text{ atm}$$

4.6

$$V_2 = V_1 \frac{T_2}{T_1} \frac{p_1}{p_2} = 4.13 \text{ L} \left(\frac{212 + 460}{32 + 460} \right) \left(\frac{14.7}{31.2} \right)$$

$$= \boxed{2.658 \text{ L}}$$

4.7



70°F
215 psia

$$460 + 70 = 530^\circ\text{R}$$

$$460 + 90 = 550^\circ\text{R}$$

atmospheric pressure = 29.92 in. Hg = std atm = 14.7 psia

$$\text{initial pressure} = \frac{200 \text{ psig} + 14.7 \text{ psia}}{14.7 \text{ psia}} \times \frac{29.92 \text{ in. Hg}}{14.7 \text{ psia}} = 437 \text{ in. Hg}$$

$$\text{final pressure} = 29.92 \text{ in. Hg} + \frac{4 \text{ in. H}_2\text{O}}{12 \text{ in. H}_2\text{O}} \times \frac{29.92 \text{ in. Hg}}{33.91 \text{ ft H}_2\text{O}}$$

(continued)

$$= 29.92 + 0.29 = 30.21 \text{ in. Hg}$$

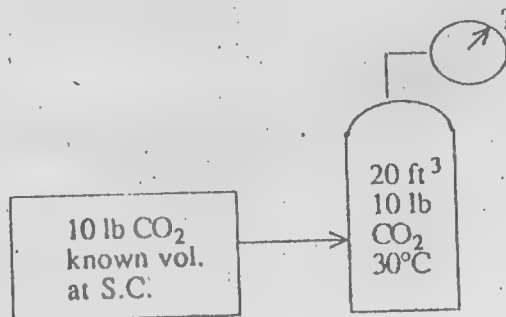
Basis: 1 ft³ of oxygen at 70°F and 200 psig

$$\begin{aligned} \text{final volume} &= \frac{1.00 \text{ ft}^3}{530^\circ\text{R}} \left| \frac{550^\circ\text{R}}{30.21 \text{ in. Hg}} \right| \frac{437 \text{ in. Hg}}{30.21 \text{ in. Hg}} \\ &= \boxed{15.0 \text{ ft}^3 \text{ at } 90^\circ\text{F and } 4 \text{ in. H}_2\text{O gauge}} \end{aligned}$$

Formally, the same calculation can be made using

$$V_2 = V_1 \left(\frac{p_1}{p_2} \right) \left(\frac{T_2}{T_1} \right) \quad \text{since } n_1 = n_2$$

4.8



Solution

We can write (the subscript 1 stands for standard conditions, 2 for the conditions in the tank)

$$p_2 = p_1 \left(\frac{V_1}{V_2} \right) \left(\frac{T_2}{T_1} \right)$$

$$\frac{14.7 \text{ psia}}{V_1} \left| \frac{10 \text{ lb CO}_2}{44 \text{ lb CO}_2} \right| \left| \frac{1 \text{ lb mol CO}_2}{1 \text{ lb mol}} \right| \frac{359 \text{ ft}^3}{20 \text{ ft}^3} \left| \frac{300\text{K}}{273\text{K}} \right| = p_2 = 66 \text{ psia}$$

Hence the gauge on the tank will read (assuming that it reads gauge pressure and that the barometer reads 14.7 psia) $66 - 14.7 = \boxed{51.3 \text{ psig}}$

4.9

Assume $\rho_{\text{H}_2\text{O}} = 62.4 \text{ lb/ft}^3$, $p_{\text{bar}} = 14.696 \text{ psia}$

$$p = \frac{500 \text{ ft H}_2\text{O}}{33.91 \text{ ft H}_2\text{O}} \left| \frac{14.696 \text{ psia}}{1} \right| + 14.696 \text{ psia} = 231.387 \text{ psia}$$

$$\hat{V} = \frac{359 \text{ ft}^3}{\text{lb mol}} \left| \frac{14.696}{231.387} \right| \left| \frac{45 + 460}{32 + 460} \right| = 23.4 \frac{\text{ft}^3}{\text{lb mol}}$$

4.10

$$pV = nRT$$

$$T = \frac{pV}{nR} = \frac{121 \text{ kPa}}{0.0011 \text{ kg mol}} \left| \frac{25 \text{ L}}{1000 \text{ L}} \right| \left| \frac{1 \text{ m}^3}{8.314 \text{ (kPa)(m}^3\text{)}} \right|$$

$$= 330.8 \rightarrow \boxed{331\text{K}}$$

4.11 Basis: 100 ppm of TCE (MW 131.5) in air

$$\rho = \frac{p \overline{MW}}{RT} \text{ where } \overline{MW} \text{ is the average MW. At 100 ppm, } \overline{MW} =$$

$$(100 \times 10^{-6})(131.5) + (1 - 100 \times 10^{-6})(29) \approx 29.$$

The density is the same as that of air.

4.12 Basis: 1 min

$$T = (68 + 460)/1.8 = 293\text{K}$$

$$MW = \text{benzene} = 78.11 \text{ g/g mol}$$

$$\rho_{\text{Bz liq}} = 0.879 \text{ g/cm}^3$$

$$pV = nRT$$

$$R = 0.08206 \text{ (L)(atm)/(g mol)(K)}$$

$$n = \frac{2.5 \text{ cm}^3 \text{ liq}}{\text{min}} \left| \frac{0.879 \text{ g Bz liq}}{1 \text{ cm}^3} \right| \left| \frac{1 \text{ g mol Bz}}{78.11 \text{ g Bz}} \right| = 0.281 \frac{\text{g mol}}{\text{min}}$$

$$V = \frac{0.0281 \text{ g mol}}{\text{min}} \left| \frac{0.08206 \text{ (L)(atm)}}{(\text{g mol})(\text{K})} \right| \left| \frac{293\text{K}}{(740/760) \text{ atm}} \right| = 0.694 \frac{\text{L}}{\text{min}}$$

To dilute to 1.0 ppm, multiply by 10^6 or use $6.94 \times 10^5 \text{ L/min}$ ($695 \text{ m}^3/\text{min}$ or $24,500 \text{ ft}^3/\text{min}$).

4.13 Basis: 1 ball

Let weight of ball = 21 oz or say 600g. The volume is 6.37L. $p = 8$ psig (1.54 atm). Let $T = 298\text{K}$

$$m = 29n = 29 \frac{pV}{RT} = \frac{1.54\text{atm}}{0.08206 \frac{(\text{L})(\text{atm})}{(\text{g mol})(\text{K})}} \left| \frac{6.37 \text{ L}}{298 \text{ K}} \right| \frac{29}{1} = 11.6 \text{ g}$$

answer: ☐ No

4.14 Basis: Vol of lungs at 10 m deep

$$\frac{p_2 V_2}{p_1 V_1} = \left(\frac{n_2}{n_1} \right) \frac{R(T_2)}{R(T_1)}$$

Assume T is constant, assume n does not change by breathing, and $p_2 = 101.3$ kPa

$$\frac{10 \text{ m}}{0.3045 \text{ m}} \left| \frac{1 \text{ ft}}{33.91 \text{ ft H}_2\text{O}} \right| \frac{101.3 \text{ kPa}}{1} = 98.0 \text{ kPa}$$

$$p_1 = (101.3 + 98.0) \text{ kPa} = 199.3 \text{ kPa}$$

$$\frac{V_2}{V_1} = \frac{p_1}{p_2} = \frac{199.3}{101.3} = 1.97$$

answer: ☐ Yes

4.15

Basis: 1 m^3 gas passing at 10°F and 1 atm. vs 60°F and 1 atm.

(assume $p_1 = p_2$), $T_1 = 520^\circ\text{R}$; $T_2 = 470^\circ\text{R}$

$$\frac{1 \text{ m}^3}{470^\circ\text{R}} \left| \frac{520^\circ\text{R}}{1} \right| = 1.105 \text{ m}^3$$

Since the moles, and mass, are directly proportional to volume at constant pressure, % increase = ☐ 10.5%

4.16

Basis: 1 m³ contaminated air (CH₃CNO MW = 57)

$$n = \frac{pV}{RT} = \frac{101.3 \text{ kPa} | 1 \text{ m}^3 | (\text{kg mol})(\text{K})}{8.314(\text{kPa})(\text{m}^3) | 293\text{K} | \frac{1000 \text{ g mol}}{\text{kg mol}}} = 41.585 \text{ g mol Air}$$

$$\frac{41.585 \text{ g mol Air}}{10^6 \text{ g mol Air}} \left| \frac{0.02 \text{ g mol CH}_3\text{CNO}}{\text{g mol CH}_3\text{CNO}} \right| \frac{57 \text{ g CH}_3\text{CNO}}{\text{g mol CH}_3\text{CNO}} \left| \frac{1000 \text{ mg}}{\text{g}} \right|$$

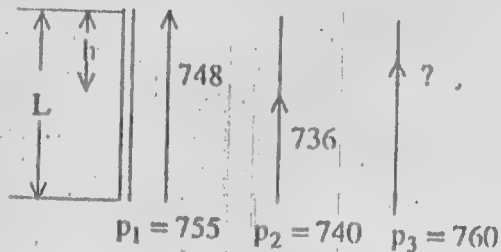
$$= 0.0474 \text{ mg CH}_3\text{CNO in 1 m}^3 \text{ of Air}$$

4.17 Basis: fixed amount of air in manometer

A = area of manometer

h = height of air, mm

L = length of manometer, mm



$$V_{\text{air}} = (h)(A)$$

$$\frac{p_1}{p_2} = \frac{V_2}{V_1} = \frac{h_2}{h_1}$$

$$p_1 = 755 - 748 = 7 \text{ mm Hg} \quad L = 748 + h_1 \quad (1)$$

$$p_2 = 740 - 736 = 4 \text{ mm Hg} \quad L = 736 + h_2 \quad (2) \quad 7Ah_1 = 4Ah_2$$

$$p_3 = 760 - (L - h_3) \quad 12 + h_1 = h_2 \quad (3) \quad (h_2/h_1) = 7/4 \quad (4)$$

$$\text{Solving (3) and (4): } h_1 = 16 \text{ mm} \quad L = 764 \text{ mm}$$

$$7(A)(h_1) = [760 - (L - h_3)] (A) (h_3) \quad (5)$$

Substituting values of h_1 , L in (5), one obtains:

$$h_3 = 18 \text{ mm}$$

$$\text{The height of barometer} = L - h_3 = 751 \text{ mm Hg}$$

4.18

(a) $\boxed{1.987 \text{ cal}/(\text{g mol})(\text{K})}$; (b) $\boxed{1.987 \text{ Btu}/(\text{lb mol})(^\circ\text{R})}$;

(c) $\frac{14.7 \text{ psia}}{492^\circ\text{R}} \left| \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \right| = \boxed{10.73 (\text{psia})(\text{ft}^3)/(\text{lb mol})(^\circ\text{R})}$

(d) $\frac{1.013 \times 10^5 \text{ N/m}^2}{273 \text{ K}} \left| \frac{22.4 \text{ m}^3}{1 \text{ kg mol}} \right| \left| \frac{1 \text{ J}}{1 (\text{N})(\text{m})} \right| \left| \frac{1 \text{ kg mol}}{10^3 \text{ g mol}} \right|$
 $= \boxed{8.314 \text{ J}/(\text{g mol})(\text{K})}$

(e) $\frac{1 \text{ atm}}{273 \text{ K}} \left| \frac{22,400 \text{ cm}^3}{1 \text{ g mol}} \right| = \boxed{82.06 (\text{cm}^3)(\text{atm})/(\text{K})(\text{g mol})}$

(f) $\frac{1 \text{ atm}}{492^\circ\text{R}} \left| \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \right| = \boxed{0.7302 (\text{ft}^3)(\text{atm})/(\text{lb mol})(^\circ\text{R})}$

4.19 Basis: 100 kg mol gas.

	mol	MW	kg	wt%
a) CH ₄	87	16	1392	77.5
C ₂ H ₆	12	30	360	20.0
C ₃ H ₈	1	44	44	2.5
Total	100		1796	100.0

b) composition in vol. percent = mol percent

CH₄ 87%
 C₂H₆ 12%
 C₃H₈ 1%

c) $\text{MW of gas} = \frac{1796 \text{ kg}}{100 \text{ kg mol}} = 17.96 \frac{\text{kg}}{\text{kg mol}}$

$R = 8.314 (\text{kPa})(\text{m}^3)/(\text{kg mol})(\text{K})$ $T = 9^\circ\text{C} = 282.15 \text{ K}$

$\text{no. of moles of gas} = \frac{80 \text{ kg}}{17.96 \frac{\text{kg}}{\text{kg mol}}} = 4.45 \text{ kg mol}$

$V = \frac{nRT}{p} = \frac{4.45 \text{ kg mol}}{60 \text{ kPa}} \left| \frac{8.314 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \frac{282.15 \text{ K}}{60 \text{ kPa}}$

$= \boxed{174 \text{ m}^3}$

(continued)

$$d) \quad \text{vol at SC} = \frac{nRT}{P} = \frac{4.45 \text{ kg mol} \left| \frac{8.314 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| 273.15 \text{ K}}{101.325 \text{ kPa}}$$

$$= \boxed{99.74 \text{ m}^3}$$

$$\text{density of gas} = \frac{1796 \text{ kg}}{99.74 \text{ m}^3} = \boxed{18.01 \text{ kg/m}^3}$$

$$e) \quad \text{Specific gravity} = \frac{\text{density of gas at } 9^\circ\text{C and } 600 \text{ kPa}}{\text{density of gas at SC}}$$

$$\text{density of gas at } 9^\circ\text{C and } 600 \text{ kPa} = \frac{1796 \text{ kg}}{17.40 \text{ m}^3} = \boxed{103.22 \text{ kg/m}^3}$$

$$\therefore \text{specific gravity} = \frac{103.22 \text{ kg/m}^3}{18.01 \text{ kg/m}^3}$$

$$= \boxed{5.73 \frac{\text{kg/m}^3 \text{ gas at } 9^\circ\text{C, } 600 \text{ kPa}}{\text{kg/m}^3 \text{ gas at SC}}}$$

4.20

Basis: 1 kg mol gas at 200 kPa and 40°C

$$(a) \quad R = 8.31 \frac{(\text{kPa})(\text{m}^3)}{(\text{K})(\text{kg mol})}$$

$$T = 40 + 273 = 313 \text{ K}$$

$$MW = 44 \text{ kg/kg mol}$$

$$p = 200 \text{ kPa}$$

$$\text{Density} = p(MW)/RT$$

$$= \frac{200 \text{ kPa} \left| \frac{44 \text{ kg}}{1 \text{ kg mol}} \right|}{313 \text{ K} \left| \frac{8.31 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right|} = \boxed{3.38 \text{ kg/m}^3}$$

(b) Specific gravity here is assumed to be density of propane at SC/density of air at SC.

$$\text{Sp. gr.} = \frac{p_{\text{C}_3\text{H}_8} n (MW_{\text{C}_3\text{H}_8})}{RT_{\text{C}_3\text{H}_8}} \left| \frac{p_{\text{air}} n (MW)_{\text{air}}}{RT_{\text{air}}} \right| = \frac{MW_{\text{C}_3\text{H}_8}}{MW_{\text{air}}} = \frac{44}{29} = \boxed{1.52}$$

4.21

Basis: 1 lb mol gas at 760 mm Hg and 60°F

$$\text{Sp. gr.} = \frac{P_{C_3H_8} (MW_{C_3H_8})}{RT_{C_3H_8}} \bigg| \frac{P_{air} (MW)_{air}}{RT_{air}} = \frac{800(44) \big| 520}{560 \big| 760} \frac{1}{29} = \boxed{1.49}$$

4.22

Basis: 1 m³ H₂ at 5°C and 110 kPa

$$\text{a.} \quad \frac{1 \text{ m}^3 \big| 273}{278 \big| 101.3 \text{ kPa}} \frac{1 \text{ kg mol}}{22.4 \text{ m}^3} \frac{2 \text{ kg}}{1 \text{ kg mol}} = \boxed{0.0952 \text{ kg/m}^3}$$

$$\text{b.} \quad \frac{2 \text{ kg H}_2}{1 \text{ kg mol H}_2} \bigg| \frac{1 \text{ kg mol air}}{29 \text{ kg air}} = \boxed{0.069} = \text{specific gravity}$$

4.23

Basis: 100 mol gas

(a)	Comp.	vol % = mol % = mol	mol. wt.	kg or lb	Wt. %
(b)	Methane	87.09	16.04	1,398.0	74.8
	Ethane	4.42	30.07	133.0	7.12
	Propane	1.60	44.09	70.5	3.76
	Iso-Butane	0.40	58.12	23.2	1.24
	N-Butane	0.52	58.12	30.3	1.62
	Pentanes	0.46	72.15	33.2	1.77
	Hexanes	0.29	86.17	25.0	1.33
	Heptanes +	0.06	100.20	6.0	0.32
	Nitrogen	4.76	28.02	133.5	7.14
	Carbon dioxide	0.40	44.00	17.6	0.94
	Total	100.00		1,870.3	100.04

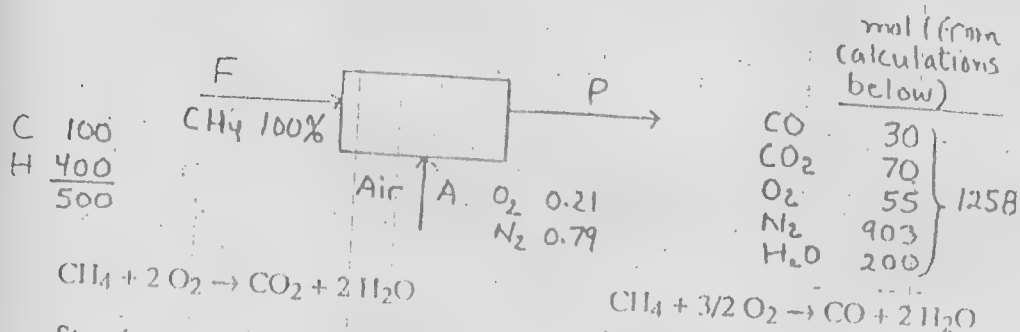
$$\text{(c)} \quad \text{Apparent molecular weight} = \frac{1,870.3}{100} = \boxed{18.70 \text{ kg/kg mol}}$$

(d) Specific gravity is relative to air at the same conditions

$$\frac{18.70}{29.00} = \boxed{0.645}$$

4.24

Steps 1, 2, 3:



Step 4: Unknowns: P and all the compositions of P (5 unknowns)

Step 5: Balances: C, H, O, N₂ + fact that 30% of C → CO

Step 6: Basis: 100 mol F

Steps 7,8:

C balance: CO = 30 mol

CO₂ = 70 mol

100 mol

N₂ balance: Reqd. O₂: 200 mol

XS O₂: 0.20 (200) = 40

Total O₂ in: 240 mol

total N₂ in = $\frac{240 \text{ O}_2}{0.21 \text{ O}_2} \cdot 0.79 \text{ N}_2 = 903 \text{ mol}$

H₂ balance: mol H₂O out = mol H₂ in = $\frac{400}{2} = 200 \text{ mol}$

O₂ balance: O₂ in - O₂ in CO, CO₂, H₂O = O₂ out

$$240 - \left(\frac{30}{2} + 70 + \frac{200}{2} \right) = 55 \text{ mol}$$

alternate: XS O₂ + O₂ not used for CO = 40 + $\frac{30}{2} = 55 \text{ mol}$

(continued)

$$P_{CO} = P_T Y_{CO}$$

$$= (740) \left(\frac{30}{1258} \right)$$

$$= \boxed{17.7 \text{ mm Hg}}$$

4.25

Basis: 15 lb N₂ + 20 lb H₂, at 50 psig, 60°F

$$\text{lb mol of N}_2 = \frac{15}{28} = 0.54$$

$$\text{lb mol of H}_2 = \frac{20}{2} = 10.00$$

$$\text{Total lb mol of the mixture} = 10.54$$

(a) Partial pressure = total pressure × mole fraction

$$\text{For nitrogen: } p_{N_2} = (50 + 14.7) \left(\frac{0.54}{10.54} \right) = \boxed{3.3 \text{ psia}}$$

$$\text{For hydrogen: } p_{H_2} = (50 + 14.7) \left(\frac{10}{10.54} \right) = \boxed{61.4 \text{ psia}}$$

$$\text{Alternatively, } p_{H_2} = (p_T - p_{N_2}) = 64.7 - 3.3 = \boxed{61.4 \text{ psia}}$$

$$(b) \text{ Specific volume} = \frac{909 \text{ ft}^3}{35 \text{ lb}} = \boxed{26 \text{ ft}^3/\text{lb}}$$

$$(c) \text{ Density} = \frac{35 \text{ lb}}{909 \text{ ft}^3} = \boxed{0.0385 \text{ lb/ft}^3}$$

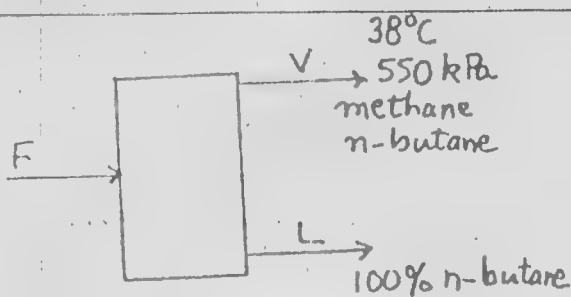
4.26 21°C = 294K

3,000 m³/day

$$P_M = 103 \text{ kPa}$$

$$P_B = 586 \text{ kPa}$$

$$P_T = 689 \text{ kPa}$$



(continued)

Basis: 1 day

mol in

$$pV = nRT$$

$$n = \frac{pV}{RT} = \frac{689 \text{ kPa} \left| 3,000 \text{ m}^3 \right|}{8.314 (\text{kPa})(\text{m}^3)} \frac{(\text{kg mol})(\text{K})}{294 \text{ K}} = 845.635 \text{ kg mol/day}$$

$$y = \frac{p}{p_T} \quad y_B = \frac{586 \text{ kPa}}{689 \text{ kPa}} = 0.8505 \frac{\text{mol C}_4\text{H}_{10}}{\text{mol feed}}$$

mol C₄H₁₀ out

$$L = \frac{845.635 \text{ kg mol F}}{\text{day}} \left| \frac{0.8505 \text{ mol C}_4\text{H}_{10}}{\text{mol feed}} \right| \frac{0.8 \text{ mol C}_4\text{H}_{10}}{\text{mol C}_4\text{H}_{10} \text{ feed}} =$$

$$\boxed{575.35 \frac{\text{mol C}_4\text{H}_{10}}{\text{day}}}$$

overall mol balance

$$F = L + V$$

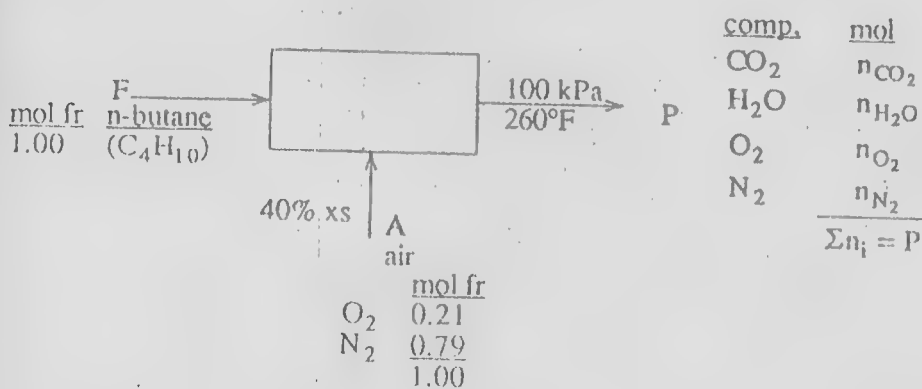
$$V = F - L = 845.635 - 575.35 = 270.26 \text{ kg mol}$$

$$pV = nRT$$

$$V = \frac{nRT}{p} = \frac{270.26 \text{ kg mol} \left| 8.314 (\text{kPa}) (\text{m}^3) \right| 311 \text{ K}}{(\text{kg mol}) (\text{K}) \left| 550 \text{ kPa} \right|} = \boxed{1,270.57 \text{ m}^3}$$

4.27 Steps 1, 2, 3, 4:

Steady state problem with a reaction.



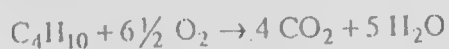
(continued)

Step 5: Basis: 1 kg mol n-butane

Step 6: Unknowns are the moles in P (4) plus P.

Step 7: The element balances are C, H, O, N, and we can use $\sum n_i = P$ so we can get a unique solution. You can use element balances or compound balances.

Step 4: Calculate A given the 40.0% excess air.



In

$$\frac{1.00 \text{ kg mol C}_4\text{H}_{10}}{1 \text{ kg mol C}_4\text{H}_{10}} \left| \frac{6\frac{1}{2} \text{ kg mol O}_2}{1 \text{ kg mol C}_4\text{H}_{10}} \right| = 6.5 \text{ kg mol O}_2$$

$$6.5(0.40) = 2.60 \text{ kg mol O}_2 \text{ xs}$$

$$= 9.10 \text{ kg mol O}_2 \text{ total}$$

$$9.10 \left(\frac{0.79}{0.21} \right) = 34.23 \text{ kg mol N}_2$$

Steps 7, 8, and 9:

Balances (kg mol)

	In	=	Out	
C:	1(4)	=	n_{CO_2}	$n_{\text{CO}_2} = 4$
H:	1(10)	=	$n_{\text{H}_2\text{O}}(2)$	$n_{\text{H}_2\text{O}} = 5$
O ₂	9.10	=	$n_{\text{CO}_2} + n_{\text{O}_2} + \frac{n_{\text{H}_2\text{O}}}{2}$	$n_{\text{O}_2} = 2.6$
N ₂	34.23	=	n_{N_2}	$n_{\text{N}_2} = 34.23$

$$P = 4 + 5 + 2.6 + 34.23 = 45.83 \text{ kg mol}$$

$$V = \frac{nRT}{p} = \frac{52.43 \text{ kg mol}}{101.3 \text{ kPa}} \left| \frac{8.314 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \frac{533.1 \text{ K}}{1}$$

$$= 2.294 \times 10^3 \text{ m}^3$$

(continued)

a.	flue gas analysis	kg mol	mol%
	CO ₂	4	9
	H ₂ O	5	11
	O ₂	2.6	6
	N ₂	34.23	75
		45.83	100

4.28 Process: Steady state with reaction, recycle

Step 5: Basis: 1 min 260L C₆H₆
 950L H₂



Convert L $\rightarrow$ mol

find $n = \frac{pV}{RT}$ $p = 150 \text{ kPa}$

$n_{H_2} = 45.95 \text{ kg mol}$ $T = 100^\circ\text{C} + 273 = 373\text{K}$

$n_{C_6H_6} = 12.58 \text{ kg mol}$ $R = 8.314 \frac{(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}$

Select the overall system for the first balances.

	In	–	Out	+	generation	–	Consumption	=	0
H ₂ :	45.85	–	$\dot{n}_{H_2}$	+	0	–	0.75(45.95)	=	0
C ₆ H ₆ :	12.58	–	$\dot{n}_{C_6H_6}$	+	0	–	0.75(45.95) ^{1/3}	=	0
C ₆ H ₁₂ :	0	–	$\dot{n}_{C_6H_{12}}$	+	0.75(45.95) ^{1/3}	–	0	=	0

from 1: $n_{H_2}^0 = 11.5$ mols

from 2: $n_{\text{C}_6\text{H}_6} = 1.1 \text{ mols}$

from 3: $n_{C_6H_{12}}^o = 11.5 \text{ mols}$

(continued)

- b. Volumetric flow rates: $T = 200^\circ\text{C} = 473\text{K}$
 $P = 100\text{ kPa} = 0.987\text{ atm}$

$$V_{\text{H}_2} = \frac{(n_{\text{H}_2}^\circ)(RT)}{P} = 452\text{ liters}$$

$$V_{\text{C}_6\text{H}_6} = 43.3\text{ liters}$$

$$V_{\text{C}_6\text{H}_{12}} = 452\text{ liters}$$

- c. H_2 balance on Reactor + Separator

$$\text{H}_2: (45.95 + 0.90R) - (0.90R + n_{\text{H}_2}^\circ) + 0 - 0.48(45.95 + 0.90R) = 0$$

Substitute for $n_{\text{H}_2}^\circ$ and solve to get $R = 26.4\text{ kg mol}$

$$\text{Volumetric flow rate (R)} = \boxed{819\text{ liters/min}}$$

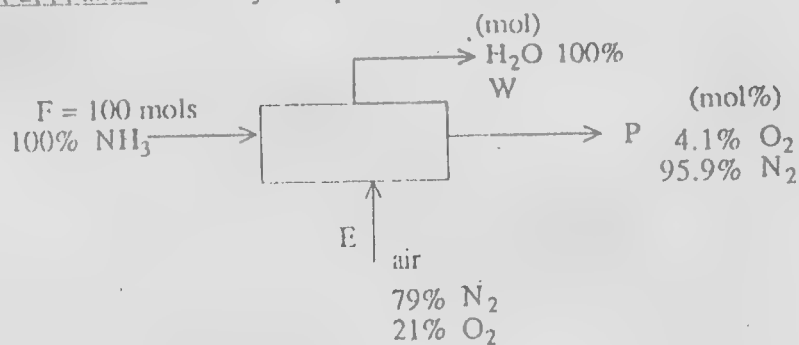
- 4.29 Basis: $p = 790\text{ mm Hg}$

$$\begin{aligned} x_2 &= 1.000 - 0.120 - 0.008 - 0.052 \\ &= 0.820 \end{aligned}$$

$$P_{\text{CO}_2} = 790(0.120) = 94.8\text{ mm Hg}$$

$$P_{\text{N}_2} = 790(0.820) = 648\text{ mm Hg.}$$

- 4.30 Steps 1, 2, 3, and 4 Steady state process with reaction.



(continued)

a) $\frac{n_{\text{air}}}{m^3 \text{NH}_3} = \frac{n_{\text{air}}}{n_{\text{NH}_3}}$ Need n_{air} and n_{NH_3}

Step 5 Basis $\Rightarrow$ 100 mols NH_3 feed.

Steps 6, 7, 8, and 9

Balance:

	In	Out
N_2 :	$0.5(100) + .79E$	$0.959P$
O_2 :	$.21E$	$0.041P + 0.5W$
H_2 :	$1.5(100)$	W

$$= 1.5(100) \quad 0.21 E = 0.041P + .5(150) \quad 50 + .79E = .959P$$

$$= 150 \text{ mol}$$

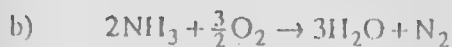
$$E = \frac{.041P + 75}{.21} \quad 50 + .79(0.195P + 357.1) = .959P$$

$$E = 0.195P + 357.1 \quad 50 + 0.154P + 282.1 = .959P$$

$$= 437.5 \quad P = 412.5$$

$$\frac{437.5 \text{ mol air}}{100 \text{ mol NH}_3} = 4.375 \frac{m^3 \text{ air}}{m^3 \text{ NH}_3}$$

$$(a) = 4.375 \frac{m^3 \text{ air}}{m^3 \text{ NH}_3}$$



$$\frac{100 \text{ mol NH}_3}{1} \left| \frac{\frac{3}{2} \text{ mol O}_2}{2 \text{ mol NH}_3} \right. = 75 \text{ mol O}_2 \text{ required}$$

$$\frac{75 \text{ mol O}_2}{1} \left| \frac{.1 \text{ mol air}}{.21 \text{ mol O}_2} \right. = 357.1 \text{ mol air required}$$

$$\text{Excess air} = \frac{\text{excess}}{\text{required}} \times 100$$

$$= \frac{(437.5 \text{ mol air} - 357.1 \text{ mol air})}{357.1 \text{ mol air}} \times 100$$

(continued)

(b) Excess air = 22.5%

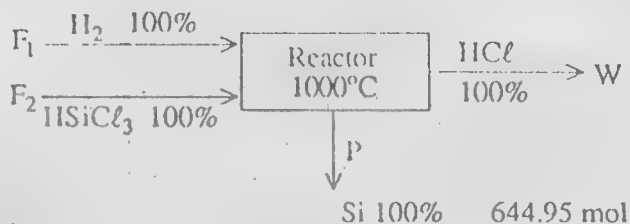
(c) Basis $\Rightarrow$ 1 min

$$\frac{20.7 \text{ m}^3 \text{ NH}_3}{1 \text{ m}^3 \text{ NH}_3} \left| \frac{4.375 \text{ m}^3 \text{ air}}{1 \text{ m}^3 \text{ NH}_3} \right| = \frac{90.6 \text{ m}^3 \text{ air @ } 40^\circ\text{C \& 125.6 kPa}}{313\text{K} \left| \frac{125.6 \text{ kPa}}{100.0 \text{ kPa}} \right|}$$

$$= 108 \text{ m}^3 \text{ @ } 25^\circ\text{C \& 100 kPa}$$

(c) Flow rate = $108 \text{ m}^3 \text{ air/min @ } 25^\circ\text{C \& 100.0 kPa}$

4.31



$$P = (D)(V) = D \left[\frac{\pi}{4} L (D_o^2 - D_i^2) \right] =$$

$$\frac{2.33 \text{ g}}{\text{cm}^3} \left| \frac{\pi}{4} \right| \left| \frac{100 \text{ cm}}{1} \right| \left| \frac{(10 \text{ cm})^2 - (1 \text{ cm})^2}{1} \right| \left| \frac{\text{g mol}}{28.086 \text{ g}} \right| = 644.95 \text{ g mol Si product}$$

Si balance

$$\frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{1 \text{ g mol Si}}{1 \text{ g mol HSiCl}_3} \right| = P \text{ g mol Si, hence } F_2 = P$$

H g mol balance

$$\frac{F_1 \text{ g mol H}_2}{1 \text{ g mol H}_2} \left| \frac{2 \text{ g mol H}}{1 \text{ g mol H}_2} \right| + \frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{1 \text{ g mol H}}{1 \text{ g mol HSiCl}_3} \right| = \frac{W \text{ g mol HCl}}{1 \text{ g mol HCl}} \left| \frac{1 \text{ g mol H}}{1 \text{ g mol HCl}} \right|$$

Cl mol balance

$$F_1(0) + \frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{3 \text{ g mol Cl}}{1 \text{ g mol HSiCl}_3} \right| = \frac{W \text{ g mol HCl}}{1 \text{ g mol HCl}} \left| \frac{1 \text{ g mol Cl}}{1 \text{ g mol HCl}} \right|$$

(continued)

Solution:

$$F_2 = P = 1 \text{ g mol HSiCl}_3$$

$$3F_2 = W = 3 \text{ g mol HCl}$$

$$2F_1 + F_2 = W$$

$$F_1 = \frac{3 \text{ g mol} - 1 \text{ g mol}}{2} = 1 \text{ g mol H}_2$$

$$\frac{1 \text{ g mol H}_2}{\text{g mol Si}} \left| \frac{644.95 \text{ g mol Si}}{1 \text{ g mol Si}} \right| = 644.95 \text{ g mol H}_2$$

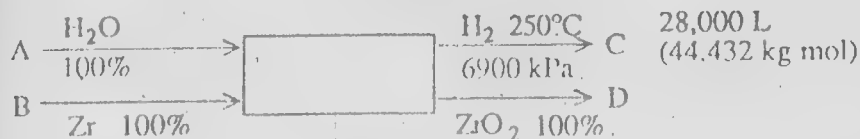
$$pV = nRT$$

$$V = \frac{nRT}{p}$$

$$= \frac{644.95 \text{ g mol} \left| \frac{82.06 (\text{cm}^3)(\text{atm})}{(\text{g mol})(\text{K})} \right| \left| \frac{1273 \text{ K}}{1 \text{ atm}} \right| \left| \frac{1 \text{ L}}{1000 \text{ cm}^3} \right|$$

$$= \boxed{67,373 \text{ L}}$$

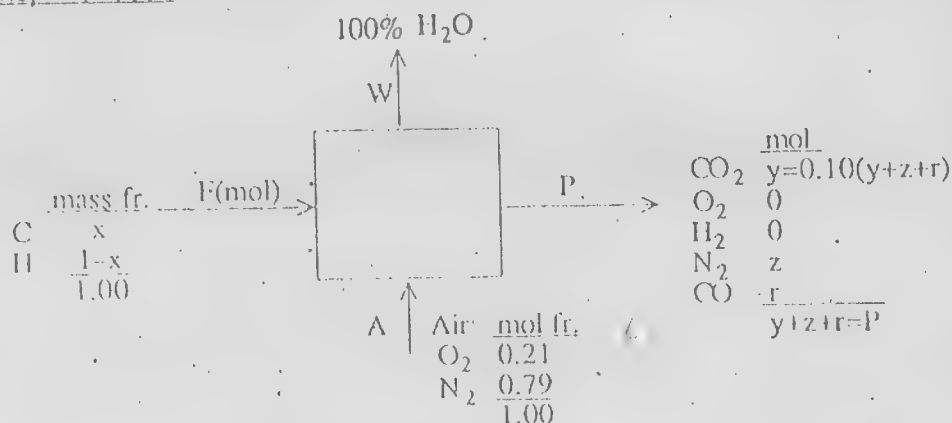
4.32 Steps 1, 2, 3, 4:

Step 5: Basis: 28,000 L of H_2 at 250°C and 6900 kPa

$$n = \frac{pV}{RT} = \frac{6,900 \text{ kPa}}{RT} \left| \frac{28,000 \text{ L}}{1000 \text{ L}} \right| \left| \frac{1 \text{ m}^3}{8.314 (\text{kPa})(\text{m}^3)} \right| \left| \frac{(\text{k mol})(\text{K})}{523 \text{ K}} \right| = 44.432 \text{ k mol H}_2$$

$$\frac{44.432 \text{ kg mol H}_2}{1 \text{ kg mol H}_2} \left| \frac{1 \text{ kg mol Zr}}{2 \text{ kg mol H}_2} \right| \left| \frac{91.22 \text{ kg Zr}}{1 \text{ kg mol Zr}} \right| = \boxed{2026 \text{ kg}}$$

4.33 Steps 1, 2, 3, 4:

Step 5: Let A be the basis so that $F = 1 \text{ lb}$ Step 6: Unknowns: W, y, z, r

Step 7: Balances C, H, N, O so 4 unknowns are possible, hence must have possibility of CO in the exhaust gas.

Basis: 173 ft^3 air at 80°F and 740 mm Hg absolute of FBasis: $1 \text{ lb fuel} = F$

Air in:

$$\frac{173 \text{ ft}^3}{80 + 460} \left| \frac{492}{760} \right| \frac{740}{359 \text{ ft}^3} \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| = 0.428 \text{ lb mol A}$$

Steps 7, 8:

$$\text{C balance: } \frac{1(x)}{12} = y + r$$

$$\text{N}_2 \text{ balance: } 0.428(.79) = z = 0.338$$

$$\text{O}_2 \text{ balance: } 0.428(.21) = y + r/2 + W/2$$

$$\text{H}_2 \text{ balance: } \frac{1(1-x)}{2} = W$$

$$y = .10(y + z + r)$$

$$.90 y = z + r$$

$$y = \frac{z+r}{0.9} = \frac{0.338+r}{0.9} = 0.376 + \frac{r}{0.9}$$

(continued)

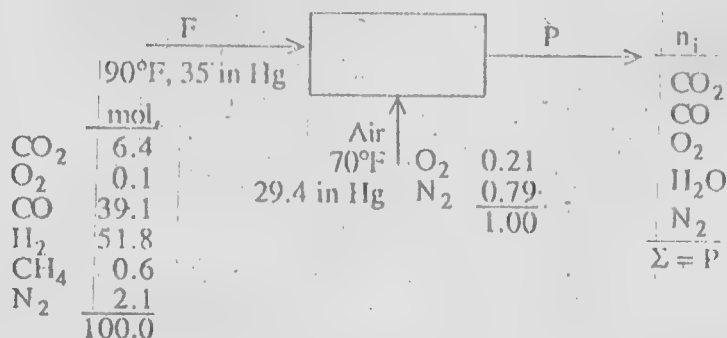
Step 9

$$\frac{x}{12} = .376 + \frac{r}{.9} + r \quad r = \frac{\frac{x}{12} - .376}{2.11}$$

$$0.0899 = .376 + \frac{r}{.9} + \frac{r}{2} + \frac{1}{2} \left(\frac{1-x}{2} \right)$$

$$x = \boxed{0.314 \frac{\text{lb H}}{\text{lb C}}}$$

4.34



4 balances can be made--plus division of C among CO and CO₂. The unknowns: n_i^P simultaneous equations not needed.

Basis: 100 mol F

	Comp.	Mol	O ₂ reqd.	rxn
(1)	CO ₂	6.4		
(2)	O ₂	0.1	-(0.1)	
(3)	CO	39.0	19.5	CO + 1/2 O ₂ → CO ₂
(4)	H ₂	51.8	25.9	H ₂ + 1/2 O ₂ → H ₂ O
(5)	CH ₄	0.6	1.2	CH ₄ + 2 O ₂ → CO ₂ + 2 H ₂ O
(6)	N ₂	2.1		
		100	46.5	
Total	xs O ₂ : (46.5)(4) =		18.6	65.1
	N ₂ entering (65.1)(.79/21) =			244.9
Total	lb mol air =			310.0

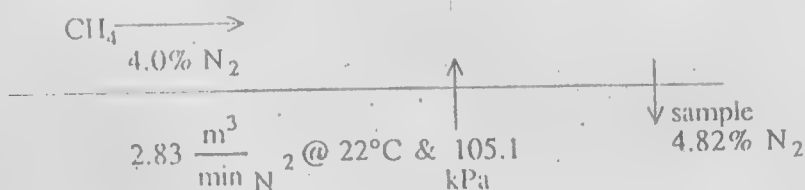
(continued)

ft³ air

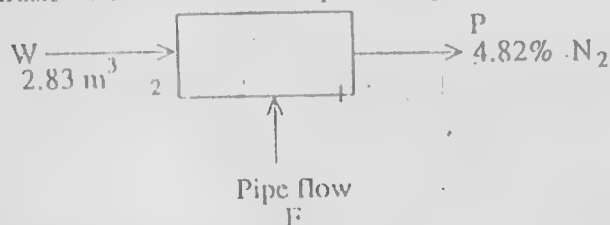
$$\frac{310 \text{ lb mol air} \left| \begin{array}{c} 359 \text{ ft}^3 \text{ at SC} \\ 1 \text{ lb mol} \end{array} \right| \begin{array}{c} 530^\circ\text{R} \\ 492^\circ\text{R} \end{array} \left| \begin{array}{c} 29.92 \text{ in. Hg} \\ 29.4 \text{ in. Hg} \end{array} \right.}{100 \text{ lb mol gas in} \left| \begin{array}{c} 359 \text{ ft}^3 \text{ at SC} \\ 1 \text{ lb mol} \end{array} \right| \begin{array}{c} 550^\circ\text{R} \\ 492^\circ\text{R} \end{array} \left| \begin{array}{c} 29.9 \text{ in. Hg} \\ 35 \text{ in. Hg} \end{array} \right.} = 3.56 \frac{\text{ft}^3 \text{ air at } 70^\circ\text{F, } 29.4 \text{ in. Hg}}{\text{ft}^3 \text{ gas at } 90^\circ\text{F, } 35 \text{ in. Hg}}$$

ft³ entering gas

4.35

Basis $\Rightarrow$ 1 min

or equivalently,

Balances:

$$\text{N}_2 \quad .04F + 2.83 = .0482P$$

$$\text{CH}_4 \quad .96F = 0.9518P$$

$$.04F + 2.83 = 0.482P \quad F = \frac{0.9518P}{.96}$$

$$.04 \left(\frac{.9518P}{.96} \right) + 2.83 = 0.482P$$

$$F = \frac{6.35 \text{ m}^3/\text{min} @ 22^\circ\text{C} \& 105.1 \text{ kPa}}{295\text{K}} \left| \begin{array}{c} 273.15\text{K} \\ 295\text{K} \end{array} \right| \frac{105.1 \text{ kPa}}{101.325 \text{ kPa}}$$

(continued)

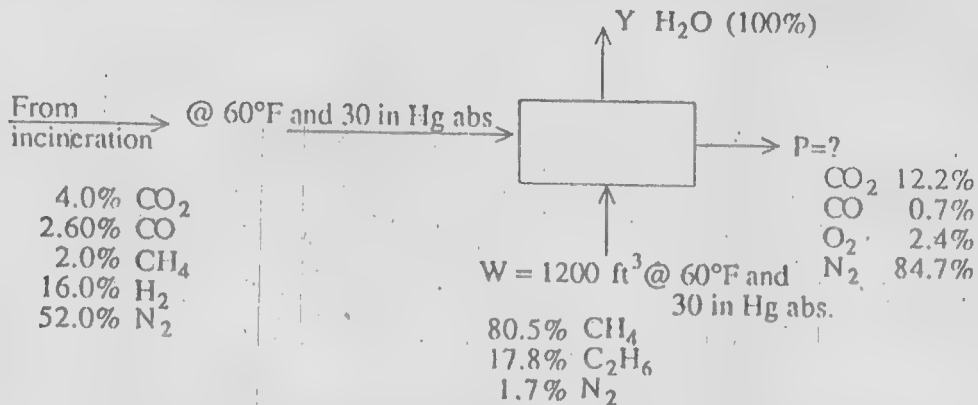
$$2.83 = 0.482P - \frac{0.04(.9518)}{.96}P$$

$$P = 610 \text{ m}^3/\text{min} @ \text{SC}$$

$$P = 6.40 \text{ m}^3/\text{min} @ 22^\circ\text{C} \text{ \& } 105.1 \text{ kPa}$$

Flow rate in pipeline before N_2 addition = $6.10 \text{ m}^3/\text{min} @ \text{SC}$

4.36



Step 1, 2, 3, and 4: Steady state process with reaction.

Step 5: Basis: 1 min.

Step 6, 7, 8, 9:

Element balance: have C, H, O, N, and have 4 unknowns P, Y, F, A.

Basis: 1200 ft^3 of W at 60°F and 30 in. Hg

	F_{in}	A_{in}	W_{in}	Y_{out}	P_{out}	
C:	$(0.04 + 0.26 + 0.02) F +$	0	$+(0.805 + 2 \times 0.178) W$	$- 0$	$-(0.122 + 0.007) P$	$= 0$
N ₂ :	$(0.52) F$	$+ 0.79 A$	$+ 0.017 W$	$- 0$	$-(0.847) P$	$= 0$
H ₂ :	$(0.04 + 0.16) F$	$+ 0$	$+(1.61 + 0.534) W$	$- Y$	0	$= 0$
O:	$(0.08 + 0.26) F$	$+ 0.42 A$	$+ 0$	$- Y$	$-(0.244 + 0.007 + 0.048) P$	$= 0$

Introduce $W = 1200 \text{ ft}^3$

C:	$0.32 F$	$+ 0$	$+ 1393.2 \text{ ft}^3$	$- 0$	$- 0.129 P$	$= 0$
N ₂ :	$0.52 F$	$+ 0.79 A$	$+ 20.4 \text{ ft}^3$	$- 0$	$- 0.847 P$	$= 0$
H ₂ :	$0.20 F$	$+ 0$	$+ 2572.8 \text{ ft}^3$	$- Y$	$- 0$	$= 0$
O:	$0.34 F$	$+ 0.42 A$	$+ 0$	$- Y$	$- 0.299 P$	$= 0$

(continued)

Solve: $F = 3,975 \text{ ft}^3$

$A = 19,510 \text{ ft}^3$

$Y = 3,370 \text{ ft}^3$

$P = 20,660 \text{ ft}^3$

$$\text{Air in} = \frac{19,510 \text{ ft}^3 @ 60^\circ\text{F} \& 30 \text{ inches Hg}}{\frac{540^\circ\text{R}}{520^\circ\text{R}} \frac{30 \text{ inches Hg}}{29.6 \text{ inches Hg}}}$$

$$= 20,535 \text{ ft}^3$$

4.37

Basis: 1 lb mol H_2 and $\text{C}_2\text{H}_4\text{O}$

$p_1 V_1 = n_1 R T_1$

$p_2 V_2 = n_2 R T_2$

$T_1 = T_2$

$$\frac{p_1}{p_2} = \frac{n_1}{n_2} \quad \frac{760 \text{ mm Hg}}{700 \text{ mm Hg}} = \frac{1}{n_2} \text{ hence } n_2 = 0.922 \text{ lb mol}$$

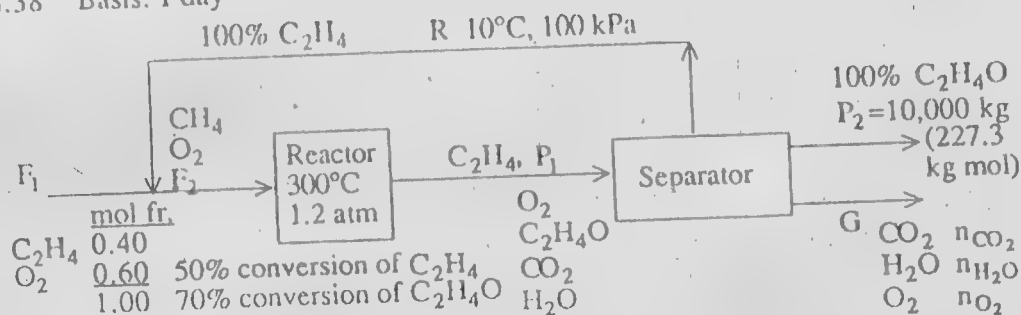
Let y = mol of $\text{C}_2\text{H}_6\text{O}$ formed

$$(0.5 - y) + (0.5 - y) + y = 0.922$$

from which $y = 0.078 \text{ lb mol } \text{C}_2\text{H}_6\text{O}$ formed

$$\text{Degree of completion} = \frac{0.078}{0.50} \times 100 = 15.6\%$$

4.38 Basis: 1 day



If the overall system is chosen, the unknowns are F_1 and n_i , and three independent equations can be written from C, H, and O balances plus $n_{\text{CO}_2} = n_{\text{H}_2\text{O}}$.

-- Pick the system of the reactor plus separator, and use the data for the conversion. (continued)

Mixing point: $F_1 + R = F_2 \Rightarrow 0.40F_1 + R = n_{C_2H_4}^{F_2}$, $0.60F_1 = n_{O_2}^{F_2}$. Unknowns: $F_1, F_2, R, n_{O_2}^{F_2}, n_{C_2H_4}^{F_2}$

Reactor plus separator:

$$C_2H_4 \text{ balance: } \left[\overset{\text{in}}{0.4(F_1) + R} \right] - \overset{\text{out}}{R} - \overset{\text{consumed}}{[0.4(F_1) + R]0.5} = 0$$

$$C_2H_4O \text{ balance: } 0 - 227.3 + \overset{\text{generation}}{[F_1(0.4) + R](0.50)(0.70)} = 0$$

$$F_1 = 811.79 \text{ kg mol/day}$$

$$R = 324.7 \text{ kg mol/day}$$

$$F_1 + R = F_2 = 1136.49$$

$$(a) \frac{1136.5 \text{ kg mol}}{\text{day}} \left| \frac{22.40 \text{ m}^3 \text{ at SC}}{1 \text{ kg mol}} \right| \frac{1 \text{ day}}{24 \text{ hr}} = \boxed{1059 \text{ m}^3 \text{ at SC/hr}}$$

$$(b) \frac{324.71 \text{ kg mol of } C_2H_4 \text{ in } R}{(811.79)(0.40) \text{ kg mol of } C_2H_4 \text{ in } F_1} \left| \frac{22.40 \text{ m}^3 \text{ at SC}}{22.40 \text{ m}^3 \text{ at SC}} \right| \overset{\text{adjust recycle}}{\left| \frac{283 \text{ K}}{273 \text{ K}} \right| \left| \frac{101.3 \text{ kPa}}{100 \text{ kPa}} \right|} = \boxed{1.05}$$

Overall balances (kg mol): unknowns n_i^{tr} (3)

Balances (3)

$$C: \quad \overset{F_1}{811.79} (.40) (2) = 227.3 (2) + n_{CO_2}$$

$$n_{CO_2} = 194.83$$

$$H: \quad 811.79 (.40) (4) = 227.3 (4) + n_W (2)$$

$$n_W = 194.83$$

$$O: \quad 811.79 (.60) (2) = 227.3 (1) + 194.83 (2) + 194.83 (1) + n_{O_2} (2)$$

$$n_{O_2} = 81.18$$

$$G = 194.83 + 194.83 + 81.18 = 470.84$$

$$\frac{470.84 \text{ kg mol } P_2}{\text{day}} \left| \frac{22.4 \text{ m}^3 \text{ at SC}}{\text{kg mol}} \right| \left| \frac{353}{273} \right| \left| \frac{101.3}{100} \right|$$

$$(c) = \boxed{1.38 \times 10^4 \text{ m}^3 \text{ gases/day at } 80^\circ\text{C and } 100 \text{ kPa}}$$

4.39

$$p_c = \frac{72.9}{1 \text{ atm}} \frac{101.3 \text{ kPa}}{1 \text{ atm}} = 7384.8 \text{ kPa}$$

$$= 7.3848 \times 10^6 \text{ Pa}$$

$$p_r = \frac{p}{p_c}$$

$$p = \frac{ZnRT}{V} \quad R = 8.314 \frac{\text{Pa m}^3}{(\text{g mol})(\text{K})}$$

$$\hat{V} = \frac{v}{n} = \frac{10.4 \text{ m}^3}{9.58 \times 10^3 \text{ g mol}} = 1.09 \times 10^{-3} \frac{\text{m}^3}{\text{g mol}}$$

$$T_c = 304.2 \text{ K}$$

$$T_r = \frac{T}{T_c} = \frac{290 \text{ K}}{324.2 \text{ K}} = 0.953$$

$$\hat{V}_c = \frac{RT_c}{p_c} = \frac{(8.314)(304.2)}{7.3848 \times 10^6} = 3.425 \times 10^{-4} \frac{\text{m}^3}{\text{g mol}}$$

$$\hat{V}_r = \frac{\hat{V}}{\hat{V}_c} = \frac{1.09 \times 10^{-3}}{3.425 \times 10^{-4}} = 3.183$$

From the compressibility charts,

$$Z = 0.88$$

$$p = \frac{ZnRT}{V} = \frac{ZRT}{\hat{V}} = \frac{0.88 \left(8.314 \frac{(\text{Pa})(\text{m}^3)}{(\text{g mol})(\text{K})} \right) (290 \text{ K})}{1.09 \times 10^{-3} \text{ m}^3/\text{g mol}}$$

4.40

$$p_c = 7384.8 \text{ kPa} \quad R = 8.314 \frac{(\text{Pa})(\text{m}^3)}{(\text{g mol})(\text{K})}$$

$$T_c = 304.2 \text{ K} \quad T = 290 \text{ K}$$

$$p_r = \frac{p}{p_c} = \frac{1200}{7384.8} = 0.1625 \quad p = 1200 \text{ kPa}$$

(continued)

$$T_r = T/T_c = 290/304.2 = 0.9533$$

$$z = 0.92$$

$$\hat{V} = \frac{RT}{p} = \frac{0.92(8.314) \frac{(\text{Pa})(\text{m}^3)}{(\text{g mol})(\text{K})}(290\text{K})}{1.200 \times 10^6 \text{ Pa}} = 1.848 \times 10^{-3} \frac{\text{m}^3}{\text{g mol}}$$

$$\hat{V} = v/n = \frac{10.4 \text{ m}^3}{n} = 1.848 \times 10^{-3} \frac{\text{m}^3}{\text{g mol}}$$

$$n = 5.626 \times 10^3 \text{ g mol}$$

$$n = \frac{5.62 \times 10^3 \text{ g mol}}{1 \text{ g mol}} \left| \frac{48 \text{ g}}{1 \text{ g mol}} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| = \boxed{270.1 \text{ kg CO}_2}$$

- 4.41 The answer is it depends on the gas temperature and the pressure. If $pV = ZnRT$ applies, the ideal gas law is represented by $Z = 1$, and for a non-ideal gas, Z can be greater or less than 1. The pressure is $p = \frac{ZnRT}{V}$. So $p_{\text{real}} = p_{\text{ideal}} Z$, for fixed V and for a fixed number of moles and temperature (the volume of cylinder is fixed, the pressure prediction by the ideal gas law will be true pressure for $Z < 1$, lower than the true pressure for $Z > 1$).

4.42 a) $p_1 V_1 = z_1 n_1 RT$ $R = \text{constant}$

$p_2 V_1 = z_2 n_2 RT_1$ $V_1 = \text{constant} - \text{vol. of cylinder}$

$$\frac{p_1}{p_2} = \frac{z_1 n_1}{z_2 n_2} \quad T_c = 133.0 \text{ K}$$

$$T_r = T/T_c = \frac{24.44 + 273}{133} = 2.24 \quad p_c = 34.5 \text{ atm}$$

$$p_{r1} = \frac{2000 \text{ psig} + 14.7}{14.7 \text{ psig/atm}} \left| \frac{1}{34.5 \text{ atm}} \right| = 3.97$$

$$p_{r2} = 3.80$$

(continued)

$$\left. \begin{array}{l} z_1 = 1.0 \\ z_2 = 1.0 \end{array} \right\} \text{Ideal gas behavior}$$

$$\frac{p_1}{p_2} = \frac{n_1}{n_2} \frac{1.0}{1.0} = \frac{n_1}{n_2}$$

$$n_{\text{CO}} = \frac{pV}{RT} = \frac{14.7 \text{ psia}}{536^\circ\text{R}} \left| \frac{175 \text{ ft}^3}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})}} \right| = 0.447 \text{ lb mol}$$

$$V_{\text{cylinder}} = \frac{n_{\text{CO}}RT_1}{p_1}$$

$$V_c = \frac{0.447 \text{ lb mol}}{2014.7 \text{ psia}} \left| \frac{10.73(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})} \right| \frac{536^\circ\text{R}}{1} = 1.276 \text{ ft}^3$$

$$n_{\text{final,CO}} = \frac{p_2 V_c}{RT} = \frac{1924.7 \text{ psia}}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})}} \left| \frac{1.276 \text{ ft}^3}{536^\circ\text{R}} \right| = 0.427 \text{ lb mol}$$

$$n_{\text{CO, lost}} = (0.447 - 0.427) \text{ lb mol} = 0.020 \text{ lb mol}$$

$$\text{rate of loss} = \frac{0.020 \text{ lb mol}}{48 \text{ hr}} = 4.167 \times 10^{-4} \frac{\text{lb mol}}{\text{hr}}$$

$$\text{b) } n_{\text{air}} = \frac{pV}{RT} = \frac{14.7 \text{ psia}}{536.0^\circ\text{R}} \left| \frac{1600 \text{ ft}^3}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})}} \right| = 4.09 \text{ lb mol air}$$

$$100 \text{ ppm} = 100 (10^{-6})(4.09 \text{ lb mol}) = 4.09 \times 10^{-4} \text{ lb mol}$$

$$z = \frac{4.09 \times 10^{-4}}{4.167 \times 10^{-4} \frac{\text{lb mol}}{\text{hr}}} = 0.982 \text{ hr}$$

(continued)

$$C_{CO} = \frac{4.375 \times 10^{-5} \text{ mol}}{1600 \text{ ft}^3} = \boxed{2.73 \times 10^{-8} \text{ mol/ft}^3}$$

- 4.43 a) The density of the gas must be 2.0 g/cm^3 . MW of Si is 28.086 so $\hat{V} = (2/28.086) = 0.0699 \text{ g/mol/cm}^3$. Let $T = 298\text{K}$. Also $z = 1$ at $T_r = 1.98$ and V_r very large.

$$p = \frac{zRT}{\hat{V}} = \frac{1 \left[\frac{8.314 (\text{Pa})(\text{m}^3)}{(\text{g mol})(\text{K})} \right] \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \frac{298 \text{ K}}{0.0699} = 2.48 \times 10^9 \text{ Pa}$$

- b) For a lower pressure, use denser gas such as Xenon or Fluorocarbons.
c) At too high a temperature, you cannot get adequate density.

- 4.44 Basis: 240 ft^3 methane at 80°F and 1964.7 psia . Assume the number of moles does not change.

$$\frac{p_1 V_1}{p_2 V_2} = \frac{nRT_1 z_1}{nRT_2 z_2}$$

$$\frac{p_1}{p_2} = \frac{T_1 z_1}{T_2 z_2}$$

$$T_2 = \frac{T_1 z_1 p_2}{z_2 p_1}$$

Calculation of z_1

$$\text{Methane} \Rightarrow T_c = 190.7\text{K} \quad p_c = 45.8 \text{ atm}$$

$$T_1 = 80^\circ\text{F} \Rightarrow 299.82\text{K}$$

$$T_r = \frac{299.82\text{K}}{190.7\text{K}} = 1.572$$

$$p_r = \frac{133.7 \text{ atm}}{45.8 \text{ atm}} = 2.919$$

(continued)

$$\therefore z_1 = 0.83$$

Calculation of z_2

$$p_1 = (1950 \text{ psig} + 14.7 \text{ psia}) \left(\frac{1 \text{ atm}}{14.7 \text{ psia}} \right) = 133.7 \text{ atm}$$

$$p_2 = (3000 \text{ psig} + 14.7 \text{ psia}) \left(\frac{1 \text{ atm}}{14.7 \text{ psia}} \right) = 205.08 \text{ atm}$$

$$p_r = \frac{205.08 \text{ atm}}{45.8 \text{ atm}} = 4.478$$

$$V = 240 \text{ ft}^3 \left(2.832 \times 10^{-2} \text{ m}^3 / \text{ft}^3 \right) \left(100 \text{ cm}^3 / 1 \text{ m}^3 \right) \\ = 6.797 \times 10^6 \text{ cm}^3$$

$$\hat{V}_{c_i} = \frac{RT_c}{p_c} = \frac{82.06 (\text{cm}^3) (\text{atm}) / (\text{g mol}) (\text{K}) (190.7 \text{ K})}{45.8 \text{ atm}}$$

$$= 341.68 \frac{\text{cm}^3}{\text{g mol}}$$

$$n = \frac{p_1 V_1}{z_1 R T_1} = \frac{(45.8 \text{ atm}) (6.797 \times 10^6 \text{ cm}^3)}{(299.82 \text{ K}) (82.06) (0.83)} \\ = 15244.5 \text{ g mol}$$

$$\therefore \hat{V} = \frac{V}{n} = \frac{6.797 \times 10^6 \text{ cm}^3}{15244.5 \text{ g mol}} = 445.87 \frac{\text{cm}^3}{\text{g mol}}$$

$$\therefore V_{t_i} = \frac{\hat{V}}{\hat{V}_{c_i}} = \frac{445.87}{341.68} = 1.305$$

$$\therefore z_2 = 1.06$$

$$T_2 = \frac{T_1 z_1 p_2}{z_2 p_1} = \frac{540^\circ \text{R} (0.83) (3014.7 \text{ psia})}{1.06 (1964.7 \text{ psia})}$$

$$T_2 = 648.8^\circ \text{R}$$

4.45 Use $pV = znRT$ $p_c = 37.2 \text{ atm}$, $T_c = 132.5 \text{ K}$

@ state 2 $p_2 = \frac{142.9}{37.2} = 3.84$ $T_2 = \frac{300}{132.5} = 2.26$

@ state 3 $p_3 = \frac{142.9}{37.2} = 3.84$ $T_3 = \frac{973}{132.5} = 7.34$

$z_2 \approx 0.99$

$z_3 = 1.05$

$$\frac{n_3}{n_2} = \left(\frac{p_2}{p_3} \right) \left(\frac{V_3}{V_2} \right) \left(\frac{R}{R} \right) \frac{(300)(0.99)}{973(1.05)} = 0.29$$

4.46 a) Yes

b) No

c) No

d) No

e) Yes

f) No

4.47 $p\hat{V} = zRT$

$$z = \frac{p\hat{V}}{RT} = \frac{(1250 \text{ atm}) \left(\frac{100 \text{ ft}^3}{95.1 \text{ lb mol}} \right)}{\left(0.7302 \frac{(\text{atm})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})} \right) (440 + 460)} = 2.00$$

$$p_r = \frac{1250 \text{ atm}}{50 \text{ atm}} = 25$$

From the Nelson & Obert graphs:

$$T_r = \frac{T}{T_c} = 1.8$$

(continued)

$$T_c = \frac{T}{1.8} = \frac{900^\circ\text{R}}{1.8} = \boxed{500^\circ\text{R or } 40^\circ\text{F}}$$

4.48

From the Nelson & Obert Charts: at SC $z = 1.00$

$$P_r = \frac{50}{14.3} = 3.5$$

$$T_r = \frac{600}{40.0 + 460} = 1.2$$

$$z = 0.58$$

$$Q = \frac{100,000 \text{ std ft}^3}{\text{hr}} \left| \frac{1 \text{ lb mol}}{359 \text{ std ft}^3} \right| \left| \frac{359(0.58) \text{ act ft}^3}{1 \text{ lb mol}} \right| \left(\frac{1}{50} \right) \frac{600}{492} = \boxed{1415 \text{ actual ft}^3/\text{hr}}$$

or use $pV = znRT$ twice

$$\frac{p_2 V_2}{p_1 V_1} = \frac{z_2 n_2 R T_2}{z_1 n_1 R T_1}$$

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{p_1}{p_2} \right) \left(\frac{z_2}{z_1} \right)$$

$$= 100,000 \left(\frac{600}{492} \right) \left(\frac{1}{50} \right) \left(\frac{0.58}{1.00} \right)$$

$$= 1415 \text{ actual ft}^3/\text{hr}$$

4.49

Basis: initial gas at 200 psig and final gas at 1000 psig

$$\text{MW } \text{C}_2\text{H}_4 = 28$$

$$P_{r1} = \frac{\text{initial } 214.7/14.7}{50.5} = 0.290$$

$$P_{r2} = \frac{\text{final } 1015/14.7}{50.5} = 1.37$$

$$T_{r1} = 1.05$$

$$T_{r2} = 1.05$$

$$z_1 = 0.90$$

$$z_2 = 0.35$$

Use $pV = znRT$

$$\frac{n_2}{n_1} = \frac{p_2}{p_1} \left(\frac{z_2}{z_1} \right)^{-1} = \frac{1015}{215} \left(\frac{0.35}{0.90} \right)^{-1} = 12.14$$

(I)
(continued)

Material balance

$$W_1 + W_c = 222$$

$$W_2 + W_c = 250$$

$$W_2 - W_1 = 28 \text{ lb} \quad n_2 - n_1 = 28/28 = 1 \quad (\text{II})$$

Solve (I) and (II) to yield $n_1 = 0.089$

$$\text{and } n_2 = 1.089$$

a. Mass of gas initially = $(0.089)(28) = 2.49 \text{ lb}$

$$(28 \text{ lb})(\$0.41/\text{lb}) = \boxed{\$11.48 \text{ billing}}$$

b. Wt. of cylinder = $(222 - 2.49) \text{ lb} = \boxed{219.5 \text{ lb}}$

$$\text{c. } V = \frac{n_1 z_1 R T}{p_1} = \frac{0.089 | 0.9 | 10.73 | 298(1.8)}{214.7} = \boxed{2.17 \text{ ft}^3}$$

4.50

Basis: 33.6 lb gas



$$T = 180^\circ\text{F} (640^\circ\text{R})$$

$$p = 2400 + 14.7 = 2415 \text{ psia}$$

$$pV = znRT$$

Basis: 100 mol gas

	mol	mol.wt.	lb	
CO ₂	10	44	440	
CH ₄	40	16	640	avg. mol wt. = $\frac{2480}{100} = 24.8$
C ₂ H ₄	$\frac{50}{100}$	28	$\frac{1400}{2560}$	

$$n = \frac{33.6}{24.8} = 1.35 \text{ lb mol}$$

$$T_c' = 0.10 (304.2) + 0.40 (190.7) + 0.50 (283.1) = 248.25 \text{ K}$$

$$p_c' = 0.10 (72.9) + 0.40 (45.8) + 0.50 (50.5) = 50.86 \text{ atm}$$

(continued)

$$p_r' = \frac{p}{p_c} = \frac{2415}{(50.86)(14.7)} = 3.23$$

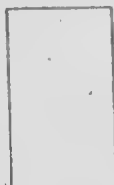
$$T_r' = \frac{T}{T_c} = \frac{640}{(248.25)(1.8)} = 1.43$$

From Fig. in text, $z \approx .77$

$$V = \frac{znRT}{p} = \frac{0.77 | 1.35 \text{ lb mol} | 10.73(\text{psia})(\text{ft}^3) | 640^\circ\text{R} |}{(\text{lb mol})(^\circ\text{R})} \bigg| 2415 \text{ psia}$$

$$= \boxed{2.96 \text{ ft}^3 \text{ at } 180^\circ\text{F, } 2415 \text{ psia of gas is cylinder volume}}$$

4.51 0.20 EtOH
0.80 CO₂
1.00



$T = 500\text{K}$
 $V = 180 \text{ cm}^3/\text{g mol}$
 $p = ?$

Basis: gas as above

$$p_c' = (0.20)(63.0) + (0.80)(72.9) = 70.92 \text{ atm}$$

$$T_c' = (0.20)(516.3) + (0.80)(304.2) = 346.6 \text{ K}$$

$$p_r' = ? = \frac{p}{p_c} = \frac{p}{70.92}$$

$$T_r' = \frac{500}{346.6} = 1.44$$

$$V_{ci}' = \frac{RT_c'}{p_c} = \frac{(1 \text{ atm})(22.4 \text{ L}) | 1000 \text{ cm}^3 | 346.6 \text{ K}}{(273 \text{ K})(1 \text{ g mol}) | 1 \text{ L} | 70.92 \text{ atm}} = 401 \text{ cm}^3/\text{g mol}$$

$$V_{ri}' = \frac{180}{401} = 0.45$$

From the compressibility chart, $p_r \approx 2.5$, $p \approx \boxed{177 \text{ atm}}$

Solutions - Chapter - 4

4.52

Basis: 540 kg gas @ 393 K, 3500 kPa absolute

	540	19.45	1.000		
C_2H_4	150	1.2	0.175	283	61.2
N_2	50	1.79	0.092	33.5	126
Total	540	19.45	1.000		

$$T_c' = (0.321)(191) + (0.412)(305) + (0.175)(370) + (0.092)(126) = 262.8 \text{ K}$$

$$p_c' = (0.321)(45.8) + (0.412)(48.2) + (0.175)(42.1) + (0.092)(33.5) = 44.96 \text{ atm}$$

$$T_r' = \frac{3.93}{262.8} = 1.50$$

$$p_r' = \frac{3500}{44.96} \left| \frac{1 \text{ atm}}{101.3} \right| = 0.77$$

From Nelson and Obert Chart, $z' = 0.935$

$$\text{MW (average)} = 540/19.45 = 27.8 \text{ kg/kg mol}$$

$$\rho = \frac{3500 \text{ kPa}}{393 \text{ K}} \left| \frac{1}{0.935} \right| \left| \frac{27.8 \text{ kg}}{\text{kg mol}} \right| \left| \frac{(\text{K})(\text{kg mol})}{8.31 (\text{kPa})(\text{m}^3)} \right|$$

$$= \frac{31.9 \text{ kg}}{\text{m}^3 \text{ at } 393 \text{ K and } 3500 \text{ kPa}}$$

4.53 (c) Use Kay's Method

$$p_{c'} = \sum n_i p_{c_i}; T_{c'} = \sum n_i T_{c_i}$$

Component	n_i	p_{c_i}	$n p_{c_i}$	T_{c_i}	$n T_{c_i}$
C_2H_4	0.57	50.5	28.8	283	61.2
A	0.40	48.0	19.2	150.7	60.2
He	0.03	10.26	0.308	13.19	0.395

$$\sum n_i p_{c_i} = 48.31$$

$$221.8$$

$$= \sum n_i T_{c_i}$$

(continued)

$$p_r' = \frac{120}{48.3} = 2.49 \quad T_r' = \frac{298}{222} = 1.342 \quad \therefore z = 0.70$$

$$V = \frac{(0.70)(82.05)(298)}{(120)} = \boxed{142.8 \text{ cm}^3/\text{g mol}}$$

$$\% \text{ diff} = \left(\frac{142.8 - 140}{140} \right) 100 = \boxed{2.00\%}$$

$$4.54 \quad \frac{460 \text{ kg CO}_2}{44 \text{ kg}} \left| \frac{1 \text{ kg mol}}{1 \text{ kg mol}} \right| \frac{1000 \text{ g mol}}{1 \text{ kg mol}} = 10.455 \times 10^3 \text{ g mol CO}_2$$

$$R = 8.314 \frac{(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}$$

$$\hat{V} = \frac{V}{n} = \frac{10.4 \text{ m}^3}{10.455 \times 10^3 \text{ g mol}} = 9.95 \times 10^{-4} \frac{\text{m}^3}{\text{g mol}}$$

$$p = \frac{(8.314)(290)}{(9.95 \times 10^{-4} - 2.97 \times 10^{-5})} - \frac{0.370}{9.95 \times 10^{-4} (9.95 \times 10^{-4} + 2.97 \times 10^{-5}) (290)^{1/2}}$$

$$= \boxed{2.48 \times 10^3 \text{ kPa}}$$

$$4.55 \quad 1.200 \times 10^6 = \frac{(8.314)(290)}{(\hat{V} - 2.97 \times 10^{-5})} - \frac{0.370}{\hat{V}(\hat{V} + 2.97 \times 10^{-5}) (290)^{1/2}}$$

$$\hat{V} = \frac{V}{n} = \frac{10.4 \text{ m}^3}{n} = 2.03 \times 10^{-3}$$

$$n_{\text{CO}_2} = 5.12 \times 10^3 \text{ g mol}$$

$$n_{\text{CO}_2} = \frac{5.12 \times 10^3 \text{ g mol}}{1 \text{ g mol}} \left| \frac{48 \text{ g}}{1000 \text{ g}} \right| \frac{1 \text{ kg}}{1000 \text{ g}}$$

$$= \boxed{246 \text{ kg CO}_2}$$

4.56

$$p = \frac{nRT}{V - nb} - \frac{n^2 a}{V^2} \quad T = 492.0^\circ\text{R}$$

$$a = \left(p - \frac{nRT}{V - nb} \right) \left(-\frac{V^2}{n^2} \right) \quad R = 0.7302 \frac{(\text{ft}^3)(\text{atm})}{(\text{lb mol})(^\circ\text{R})}$$

Basis: 1.0 lb mol

$$200 \text{ atm} = \frac{1.0 \text{ lb mol} \left[0.7302 \frac{(\text{ft}^3)(\text{atm})}{(\text{lb mol})(^\circ\text{R})} \right] 492.0^\circ\text{R}}{(1.806 \text{ ft}^3 - (1.0 \text{ lb mol})b)} - \frac{(1.0 \text{ lb mol})^2 a}{(1.86 \text{ ft}^3)^2}$$

$$200 = \frac{359.3(\text{ft}^3)(\text{atm})}{(1.860 \text{ ft}^3 - b)} - 0.2891 a$$

similarly

$$1000 = \frac{359.3(\text{ft}^3)(\text{atm})}{(0.741 \text{ ft}^3 - b)} - 1.82a$$

$$a = \left(1000 - \frac{359.3}{0.741 - b} \right) \left(-\frac{1}{1.82} \right)$$

$$200 = \frac{359.3}{(1.860 - b)} - (0.289) \left(-\frac{1}{1.82} \right) \left(1000 - \frac{359.3}{0.741 - b} \right)$$

$$200 = \frac{359.3}{(1.860 - b)} + 158.8 - \frac{57.07}{(0.741 - b)}$$

$$41.20 = \frac{359.3}{(1.860 - b)} - \frac{57.07}{(0.741 - b)}$$

$$b = 0.4808 \frac{\text{ft}^3}{\text{lb mol}}$$

$$a = 209.3(\text{atm}) \left(\frac{\text{ft}^3}{\text{lb mol}} \right)^2$$

4.57

$$a \Rightarrow (\text{atm}) \left(\frac{\text{L}}{\text{g mol}} \right)^2$$

$$b \Rightarrow \text{L/g mol}$$

$$\alpha \Rightarrow \text{dimensionless}$$

4.58 Redlich-Kwong

$$p = \frac{RT}{(\hat{V} - b)} - \frac{a}{T^{1/2} \hat{V}(\hat{V} + b)}$$

$$a = 48055.84 \text{ psia } (\text{°R})^{1/2} (\text{ft}^3/\text{lb mol})^2$$

$$b = 0.3536 \text{ ft}^3/\text{lb mol}$$

$$n = \frac{63.9}{32} = 1.997 \text{ lb mol}$$

$$\hat{V} = \frac{V}{n} = \frac{6.7}{1.997} = 3.355 \text{ ft}^3/\text{lb mol}$$

$$\text{Solving, } p = 1465 \text{ psia}$$

Therefore, the reading on the pressure gauge is incorrect.

4.60 Pressure in can $(81.0 \text{ psig} + 14.7 \text{ psia}) (1 \text{ atm}/14.7 \text{ psia}) = 6.5 \text{ atm}$

$$\text{Temperature } 25^\circ\text{C} \Rightarrow 298.15\text{K}$$

$$V = \pi(4.05 \text{ cm})^2(17.0 \text{ cm}) = 876 \text{ cm}^3$$

$$n = ? \text{ CO}_2$$



Using Peng-Robinson equation

$$n^3(ba\alpha - b^2RT - b^3p) - n^2(V)(a\alpha - 2bRT - 3b^2p) - n(V^2)(bp - RT) - V^3p = 0$$

(continued)

Equations $\Rightarrow$

$$f(n) = n^3 q - n^2 (V)(z) - n(V^2)(bp - RT) - V^3 p = 0$$

$$q = ba\alpha - b^2 RT - b^3 p$$

$$z = a\alpha - 2bRT - 2b^2 p$$

$$a = 0.45724 \frac{(R^2 T_c^2)}{P_c}$$

$$b = 0.07780(RT_c / P_c)$$

$$\alpha = \left[1 + \kappa \left(1 - (T/T_c)^{\frac{1}{2}} \right) \right]^2$$

$$\kappa = 0.37464 + 1.54226\omega - 0.26992\omega^2$$

$$R = 82.06 \text{ cm}^3 \text{ atm}/(\text{g mol}) (\text{K})$$

$$\text{IDEAL} = 0.233 \text{ mol CO}_2$$

$$T = 298.18 \text{ K}$$

$$P = 6.51 \text{ atm}$$

$$n = 0.2420 \text{ mol CO}_2$$

$$V = 876 \text{ cm}^3$$

$$f(n) = 2.0000$$

$$T_c = 304.2 \text{ K}$$

$$P_c = 27.9 \text{ atm}$$

$$\omega = 0.225$$

$$\frac{0.2320 \text{ mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{1 \text{ mol NaHCO}_3}{1 \text{ mol NaHCO}_3} \right| \frac{84.00 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3} = \boxed{20.3 \text{ g NaHCO}_3}$$

4.61

$$\left(p = \frac{RT}{(\hat{V} - b)} - \frac{a\alpha}{\hat{V}(\hat{V} - b) + b(\hat{V} - b)} \right) \left[\hat{V}(\hat{V} + b) + b(\hat{V} - b) \right]$$

$$p\hat{V}(\hat{V} + b) + pb(\hat{V} - b) = \frac{[\hat{V}(\hat{V} + b) + b(\hat{V} - b)]RT}{(\hat{V} - b)} - a\alpha$$

$$p\hat{V}(\hat{V} + b) + pb(\hat{V} - b) = \frac{[\hat{V}RT(\hat{V} + b) + bRT(\hat{V} - b)]}{(\hat{V} - b)} - a\alpha$$

$$\left[p\hat{V}(\hat{V} + b) + pb(\hat{V} - b) = \hat{V}RT \frac{(\hat{V} + b)}{(\hat{V} - b)} + bRT - a\alpha \right] (\hat{V} - b)$$

$$p\hat{V}(\hat{V} + b)(\hat{V} - b) + pb(\hat{V} - b)(\hat{V} - b) = \hat{V}RT(\hat{V} + b) + bRT(\hat{V} - b) - a\alpha(\hat{V} - b)$$

$$p\hat{V}(\hat{V}^2 - b^2) + pb(\hat{V}^2 - 2\hat{V}b + b^2) = \hat{V}^2RT + \hat{V}bRT + \hat{V}bRT - b^2RT - \hat{V}a\alpha + ba\alpha$$

$$\hat{V}^3p - \hat{V}b^2p + \hat{V}^2bp - 2\hat{V}b^2p + b^3p = \hat{V}^2RT + 2\hat{V}bRT - b^2RT - \hat{V}a\alpha + ba\alpha$$

$$\hat{V}^3p - 3\hat{V}b^2p + \hat{V}^2bp + b^3p - \hat{V}^2RT - 2\hat{V}bRT + \hat{V}a\alpha = ba\alpha - b^2RT$$

$$\hat{V}^3p + \hat{V}^2bp - \hat{V}^2RT - 3\hat{V}b^2p - 2\hat{V}bRT + \hat{V}a\alpha - ba\alpha - b^2RT - b^3p$$

$$\hat{V}^3p + \hat{V}^2(bp - RT) + \hat{V}(a\alpha - 2bRT - 3b^2p) = ba\alpha - b^2RT - b^3p$$

Match

$$n^3 \left[\left(\frac{V}{n} \right)^3 p + \left(\frac{V}{n} \right)^2 (bp - RT) + \left(\frac{V}{n} \right) (a\alpha - 2bRT - 3b^2p) - (ba\alpha - b^2RT - b^3p) \right] = 0$$

$$V^3p + nV^2(bp - RT) + n^2V(a\alpha - 2bRT - 3b^2p) - n^3(ba\alpha - b^2RT - b^3p) = 0$$

$$n^3(ba\alpha - b^2RT - b^3p) - n^2(V)(a\alpha - 2bRT - 3b^2p) - n(V^2)(bp - RT) - V^3p = 0$$

$$a = 0.45724 \left(\frac{R^2 T_c^2}{P_c} \right)$$

(continued)

$$b = 0.07780 \left(\frac{RT_c}{P_c} \right)$$

$$\alpha = \left[1 + \kappa \left(1 - T_r^{1/2} \right) \right]^2$$

$$\kappa = 0.37464 + 1.54226\omega - 0.26992\omega^2$$

$$*\omega_{\text{air}} = .21(0.021) + .79(0.040)$$

$$= .00441 + 0.0312$$

$$= 0.03561$$

*assume acentric factor for air is weighted combination of N_2 and O_2 .

Reservoir Volume = 0.3L The solution is for this value of V; n = ?

$$\text{Temp.} = -10^\circ\text{C} \Rightarrow 263.15\text{K}$$

$$\text{Pressure} = 240 \text{ atm}$$

$$T_{c,\text{air}} = 132.5\text{K}$$

$$p_{c,\text{air}} = 37.2 \text{ atm}$$

$$R = 0.08206 \text{ L (atm)/(g mol) (K)}$$

$$\text{Ideally} \Rightarrow n = pV/RT \rightarrow 240 \text{ atm}(.3\text{L}) / \left(0.08206 \frac{(\text{L})(\text{atm})}{(\text{g mol})(\text{K})} \right) (283.15 \text{ K})$$

$$= 3.33 \text{ g mol air}$$

From Polymath

$$\hat{V} = 0.936 \times 10^{-2} \text{ or } 0.1126$$

$$\hat{V} = \frac{V}{n}$$

$$f(\hat{V}) = -0.234 \times 10^{-6} \text{ or } -0.204 \times 10^{-5}$$

$$n = \frac{V}{\hat{V}}$$

(continued)

$$= \frac{.3L}{0.936 \times 10^{-2} L} \quad \text{or} \quad .3L/0.1126L$$

$$= 32.05 \text{ mols air} \quad = 2.66 \text{ mols air}$$

Answer $\Rightarrow$ 2.66 mole air

4.62 Computer results:

Redlich-Kwong: 1193.14 cm³/g mol

Peng-Robinson: 1168.91 cm³/g mol

4.63

$P_{abs} = p_g + \text{barometric pressure}$

$$T = 273 - 50 = 223 \text{ K}$$

$$P_{abs} = 39 + 1 = 40 \text{ atm}$$

Use the coefficients for van der Waals eq. from the text.

Basis: 1 g mol H₂

Computer results

van der Waals: 471.78 cm³/g mol

Redlich-Kwong: 471.26 cm³/g mol

$$\frac{5L \left| \frac{1000 \text{ cm}^3}{L} \right| \cdot 1 \text{ g mol}}{471.78 \text{ cm}} = \text{10.60 g mol (van der Waals)}$$

$$5 (1000)/471.26 = \text{10.61 g mol (Redlich - Kwong)}$$

4.64

Computer results:

Redlich-Kwong = 1559.6 cm³/g mol

$$\text{The experimental molar volume} = \frac{6250 \text{ cm}^3}{4 \text{ g mol}} = \text{1562.5 cm}^3/\text{g mol}$$

4.65

$$\begin{array}{l} \text{Basis: } T = 54.5^\circ\text{F} \\ p = 388 \text{ psig} \\ V = 2.04 \text{ ft}^3 \\ \text{CO}_2 \end{array}$$

$$a = 3.592 \frac{(\text{L}^2)(\text{atm})}{(\text{g mol})^2}$$

$$b = 0.04267 \text{ L/g mol}$$

Objective:

Find n via van der Waals' eqn.

$$54.5^\circ\text{F} \rightarrow 12.5^\circ\text{C} \\ \frac{273.0}{285.5} \text{ K}$$

If done on a calculator, proceed as follows

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

$$(V^2 p + n^2 a)(V - nb) = V^2 nRT$$

$$V^3 p - V^2 pnb + n^2 aV - n^3 ab = V^2 nRT$$

$$f(n) = n^3 ab - n^2 aV + n(V^2 pb + V^2 RT) - V^3 p = 0$$

$$f'(n) = 3n^2 ab - 2naV + (V^2 pb + V^2 RT) = 0$$

Apply Newton's method via calculator

$$n_{\text{new}} = n_{\text{old}} - \frac{f(n_{\text{old}})}{f'(n_{\text{old}})}$$

For initial n use $pV = nRT$

$$n = \frac{pV}{RT} \text{ or}$$

$$n(\text{g mol}) = \frac{2.04 \text{ ft}^3}{(470 + 54.5)^\circ\text{R}} \left| \frac{492^\circ\text{R}}{14.7} \right| \left| \frac{359 \text{ ft}^3}{1 \text{ lb}} \right| \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = 59.2 \text{ g mol}$$

$$\frac{2.04 \text{ ft}^3}{33.51 \text{ ft}^3} \left| \frac{1 \text{ m}^3}{10^2 \text{ cm}} \right|^3 = 6.088 \times 10^4 \text{ cm}^3 = 60.88 \text{ L}$$

$$\frac{352 \text{ psia}}{14.7 \text{ psia}} \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| = 24 \text{ atm}$$

(continued)

$$f(n_{old}) = \frac{(59.2 \text{ g mol})^3}{(\text{g mol})^2} \left| \frac{3.592 (\text{L}^2) (\text{atm})}{\text{g mol}} \right| \frac{0.04267 \text{ L}}{\text{g mol}}$$

$$- \frac{(59.2 \text{ g mol})^2}{(\text{g mol})^2} \left| \frac{3.592 (\text{L}^2) (\text{atm})}{\text{g mol}} \right| \frac{60.88 \text{ L}}{\text{g mol}}$$

$$+ \frac{(59.2 \text{ g mol})}{(\text{g mol})} \left| \frac{(60.88 \text{ L})^2 (24 \text{ atm}) (0.04267 \text{ L})}{\text{g mol}} \right|$$

$$+ \frac{(59.2 \text{ g mol})}{(\text{g mol})} \left| \frac{(60.88 \text{ L})^2 (285 \text{ K}) (0.08206) (\text{L}) (\text{atm})}{(\text{g mol}) (\text{K})} \right|$$

$$- \frac{(60.88 \text{ L})^3}{(\text{L}^3)} \left| \frac{24 \text{ atm}}{\text{atm}} \right| = -793819$$

$$f'(n_{old}) = \frac{3(59.2 \text{ g mol})^2}{(\text{g mol})^2} \left| \frac{(3.592) (\text{L}^2) (\text{atm})}{\text{g mol}} \right| \frac{0.04267 \text{ L}}{\text{g mol}}$$

$$- \frac{2(59.2) \text{ g mol}}{(\text{g mol})^2} \left| \frac{(3.592) (\text{L}^2) (\text{atm})}{\text{g mol}} \right| \frac{60.88 \text{ L}}{\text{g mol}}$$

$$+ \frac{(60.88 \text{ L})^2}{(\text{L}^2)} \left[\frac{(24 \text{ atm}) (0.04267 \text{ L})}{\text{g mol}} + \frac{(0.08206) (\text{L}) (\text{atm})}{(\text{g mol}) (\text{K})} \right] \frac{285 \text{ K}}{\text{K}} = 66211$$

$$n_{new} = 59.2 \text{ mol} - \frac{-773819}{66211} = 71.2 \text{ g mol}$$

Replace n_{old} with n_{new} and repeat the procedure using Newton's formula.

Final answer would be $(n_{final}) = (44 \text{ lb/lbmol}) + 52.27$

4.66

Basis: 1 lb mol CO_2

Part a--Compressibility Factor

$$p_r = \frac{p}{p_c} = \frac{(1200) \text{ atm}}{(14.7)} \left| \frac{72.9 \text{ atm}}{\text{atm}} \right| = 1.12$$

120

460

580°R = 322.2 K

(continued)

$$T_r = \frac{T}{T_c} = \frac{580^\circ\text{R}}{547.6} = 1.06$$

$$= 87.6$$

$$\frac{460.0}{547.6^\circ\text{R}}$$

$$= 81.6 \text{ atm}$$

$$\frac{1200}{14.7} = 81.6 \text{ atm}$$

$$\frac{V}{n} = \frac{zRT}{p} = \frac{0.58 \left[\frac{(14.7 \text{ psia}) (359 \text{ ft}^3)}{(492^\circ\text{R}) (1 \text{ lb mol})} \right] \frac{580^\circ\text{R}}{1200 \text{ psia}} = \frac{3.01 \text{ ft}^3 \text{ at T\&p}}{\text{lb mol CO}_2}$$

$$\frac{3.01 \text{ ft}^3}{\text{lb mol CO}_2} \left| \frac{\text{lb mol CO}_2}{1 \text{ lb mol C}} \right| \left| \frac{1 \text{ lb mol C}}{12 \text{ lb C}} \right| \left| \frac{0.74 \text{ lb C}}{1 \text{ lb coal}} \right| \left| \frac{0.08 \text{ lb coal used}}{1 \text{ lb coal transported}} \right|$$

$$= \boxed{0.0148 \text{ ft}^3 \text{ of CO}_2 \text{ at } 580^\circ\text{R} \text{ and } 1200 \text{ psia/lb coal transported}}$$

Part b--van der Waal's equation

Basis: $n = 1 \text{ g mol}$

$$\left(p + \frac{n^2 a}{V^2} \right) (V - nb) = nRT$$

$$V^3 - \left(nb + \frac{nRT}{p} \right) V^2 + \frac{n^2 a}{p} V - \frac{n^3 ab}{p} = 0$$

$$V^3 - \left[(1 \text{ g mol}) \left(42.8 \frac{\text{cm}^3}{\text{g mol}} \right) + (1 \text{ g mol}) \frac{(82.06) (\text{cm}^3) (\text{atm}) (322.2 \text{ K})}{(\text{K}) (\text{g mol}) (81.6 \text{ atm})} \right] V^2$$

$$+ \left[\frac{1 (\text{g mol})^2 (3.6 \times 10^6) (\text{atm}) (\text{cm}^6)}{(81.6 \text{ atm}) (\text{g mol})^2} \right] V - \frac{1 (\text{g mol})^3 (3.6 \times 10^6) (\text{atm}) (\text{cm}^6) (42.8) (\text{cm}^3)}{(81.6 \text{ atm}) (\text{g mol})^2 (\text{g mol})}$$

$$= 0$$

$$V^3 - 366.82 V^2 + 4.412 \times 10^4 V - 1.888 \times 10^6 = 0 = f(V)$$

$$3 V^2 - 733.64 V + 4.412 \times 10^4 = f'(V)$$

$$V_{r+1} = V_r - \frac{f(V_r)}{f'(V_r)}$$

(continued)

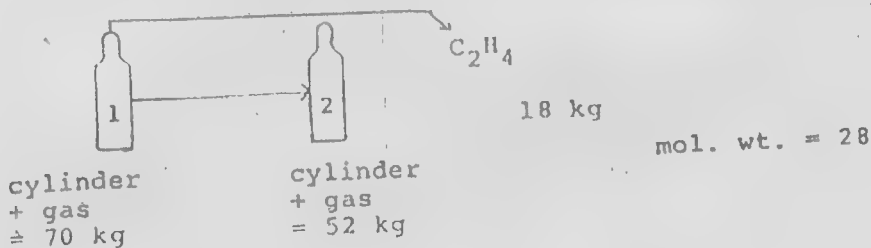
V_0 comes from part a

$$\frac{3.01 \text{ ft}^3}{\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)^3} \left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)^3 = 8.523 \times 10^{-4} \text{ cm}^3$$

$$V_1 = 8.523 \times 10^{-4} - \frac{6.164 \times 10^{-14}}{2.173 \times 10^{-10}} = 5.686 \times 10^{-4}$$

repeat procedure

4.67



(a) solution via Van der Waals Eq.:

$$p_1 = \frac{n_1 RT}{V - n_1 b} - \frac{n_1^2 a}{V^2} = 10^4 \text{ kPa}$$

$$p_1 = 10^4 \text{ kPa} \equiv 98.72 \text{ atm gauge}$$

$$= 99.72 \text{ atm absolute}$$

$$p_2 = \frac{n_2 RT}{V - n_2 b} - \frac{n_2^2 a}{V^2} = \frac{10^4}{3} \text{ kPa}$$

$$p_2 = \frac{10^4 \text{ kPa}}{3} \equiv 32.91 \text{ atm}$$

$$= 1.00$$

$$33.91 \text{ atm absolute}$$

Basis: Data in Figure

$$n_1 - n_2 = \frac{18 \text{ kg}}{28 \text{ kg}} \left| \frac{1 \text{ kg mol}}{28 \text{ kg}} \right| = 0.64 \text{ kg mol}$$

$$10^4 - \left(\frac{n_1 RT}{V - n_1 b} - \frac{n_1^2 a}{V^2} \right) = 0 \text{ and } \left[\frac{(n_1 - 0.64) RT}{V - (n_1 - 0.64) b} - \frac{(n_1 - 0.64)^2 a}{V^2} \right] - \frac{10^4}{3} = 0$$

Both n_1 and V are unknown, hence the two nonlinear equations have to be solved simultaneously for n_1 and V .

(continued)

As an approximation useful for the initial guesses use the idea gas law

$$p_1 V_1 = n_1 R T_1 \quad V_1 = V_2 \quad \frac{p_1}{p_2} = \frac{n_1}{n_2} = \frac{3}{1}$$

$$p_2 V_2 = n_2 R T_2 \quad T_1 = T_2$$

$$\frac{n_1}{n_1 - 0.64} = 3 \text{ or } n_1 \cong 0.96 \text{ kg mol and } n_2 \cong 0.32$$

$$V = \frac{n_2 R T}{p_2} = \frac{0.32 \text{ kg mol} \left| \frac{8.31 \text{ (kJ)} (\text{m}^3)}{(\text{K}) (\text{kg mol})} \right| \cdot 298 \text{ K}}{\left| (10^4 + 100) \text{ kPa} \right|} = 7.92 \times 10^{-2} \text{ m}^3$$

Either use a computer code that solves for the roots of simultaneous equations, or minimize the sum of the squares of the deviations between the functions and zero.
Results:

$$\boxed{n_1 = 0.79 \text{ kg mol}} \\ \boxed{n_2 = 0.15 \text{ kg mol}}$$

$$\boxed{V = 0.075 \text{ m}^3} \\ \boxed{n_2 / n_1 = 0.19}$$

(b) Solution via compressibility factor

State 1

$$p_{r1} = \frac{p_1}{p_c} = \frac{99.72 \text{ atm}}{50.5 \text{ atm}} = 1.97 \quad p_c = 50.5 \text{ atm}$$

$$T_c = 283.1 \text{ K}$$

$$T_{r1} = \frac{T_1}{T_c} = \frac{298 \text{ K}}{283.1 \text{ K}} = 1.05$$

$$z_1 \text{ (from compressibility chart)} = 0.34$$

State 2

$$p_{r2} = \frac{p_2}{p_c} = \frac{33.91 \text{ atm}}{50.5 \text{ atm}} = 0.65 \quad 3 \text{ unknowns: } n_1, n_2, V_1$$

$$T_{r2} = \frac{T_2}{T_c} = \frac{298 \text{ K}}{283.1 \text{ K}} = 1.05$$

$$z_2 \text{ (from compressibility chart)} = 0.79$$

• (continued)

3 equations: $n_1 = n_2 + \frac{18}{28}$

$$p_1 V_1 = n_1 z_1 R T_1$$

$$p_2 V_1 = n_2 z_2 R T_1$$

$$T_1 = \frac{298}{283.1} = 1.05$$

$$p_2 V_2 = z_2 R n T_2$$

$$p_1 V_1 = z_1 R n T_1$$

$$(a) \quad \frac{V_1}{V_2} = \left(\frac{p_2}{p_1} \right) \left(\frac{z_1}{z_2} \right) = \left(\frac{20,000}{1000} \right) \left(\frac{0.38}{2.84} \right) = \boxed{2.68}$$

$$(b) \quad \frac{V_2}{n} = \frac{z_2 R T_2}{p_2} = \frac{2.84 (10.73) (298) (1.8)}{20,000} = 0.82 \frac{\text{ft}^3}{\text{lb mol}}$$

$$\text{MW of } \text{CH}_2\text{CH}_2 = 28$$

$$\frac{1 \text{ lb mol}}{0.82 \text{ ft}^3} \left| \frac{28 \text{ lb}}{\text{lb mol}} \right| = \boxed{34.2 \frac{\text{lb}}{\text{ft}^3}}$$

4.68 The vapor pressure of methanol is less than that of gasoline so that at lower temperatures the fuel-to-air mixture is insufficient for combustion.

Automotive parts can be made of alcohol tolerant materials such as stainless steel or other corrosion resistant materials and additives to the methanol, such as 15% gasoline, can help solve the problem of difficult cold-weather engine starts.

4.69 a) Antoine eqn.

$$\ln p^* = A - \frac{B}{(C+T)} \quad T_K = T_C + 273.15$$

$$\ln(20) = A - \frac{B}{[C + (10.3^\circ\text{C} + 273.15)]} \quad p^* \text{ is in mm Hg abs.}$$

$$2.996 = A - \frac{B}{(C + 283.5\text{K})}$$

(continued)

Similarly

$$4.099 = A - \frac{B}{(C + 305.6K)}$$

$$4.605 = A - \frac{B}{(C - 317.0K)}$$

$$A = 4.605 + \frac{B}{(C + 317.0K)}$$

$$B = (A - 4.099)(C + 305.6K)$$

$$C = \left(\frac{B}{A - 2.996} \right) - 283.5K$$

$$A = 19.449$$

$$B = 5085.0$$

$$C = 25.559$$

$$\ln p^* = A - \frac{B}{(C + T)}$$

$$p^* = \boxed{804.8 \text{ mm Hg}}$$

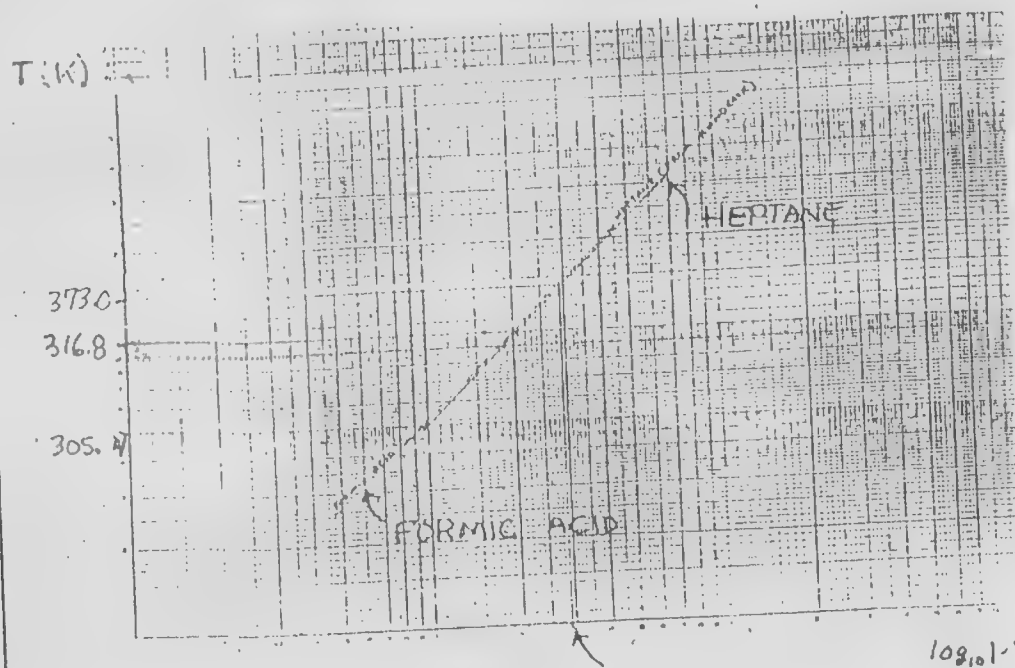
Use as the initial guess:

$$A = 15$$

$$B = 5000$$

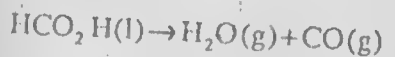
$$C = 20$$

b) Cox Chart



4.70 No. It is a typo. Probably the number was 98.8°C because if you equate the pressures from the two equations, $T = 371.75\text{K}$, or 98.7°C .

4.71



The total pressure in the volume was $p_{\text{formic acid}}^* + p_{\text{H}_2\text{O}} + p_{\text{CO}} = p_T = 210 \text{ kPa}$

$p_{\text{formic acid}}^*$ is about 42 mm Hg abs = 5.60 kPa. For each mol of CO, there is 1 mol of H_2O so that $p_{\text{CO}} = p_{\text{H}_2\text{O}}$.

$$\frac{210 - 5.60}{2} = p_{\text{CO}} = p_{\text{H}_2\text{O}} = 102 \text{ kPa}$$

$$n_{\text{CO}} = \frac{pV}{RT} = \frac{102 \text{ kPa} \left| \frac{10 \text{ cm}^3}{298 \text{ K}} \right| \left(\frac{\text{kg mol}}{\text{K}} \right) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) \left(\frac{\text{m}}{100 \text{ cm}} \right)^3}{8.314 (\text{kPa})(\text{m}^3)} = 0.41 \times 10^{-3} \text{ g mol}$$

For each g mol CO , 1 g mol formic acid decomposes

$$n_{\text{formic acid liquid}} = \frac{1.220 \text{ g} \left| \frac{1000 \text{ cm}^3}{\text{cm}^3} \right| \left| \frac{1 \text{ g mol}}{43.06 \text{ g}} \right|}{\text{cm}^3} = 28.33 \text{ g mol}$$

$$\text{fraction decomposed} = \frac{0.41 \times 10^{-3}}{28.33} = 1.45 \times 10^{-5}$$

1.72

DATA:

$\log(T)$	$(\log(T))^2$	$(\log(T))^3$	$\log p$
5.6101	31.4727	176.5329	0.61130
5.7038	32.5331	185.5619	3.53600
5.7991	33.6295	195.0204	17.21000
5.8861	34.6462	203.9313	62.15000
5.9402	35.2856	209.6027	128.80000
5.9915	35.8976	215.0795	245.60000
6.0403	36.4847	220.3767	437.00000
6.0868	37.0488	225.5079	733.20000
6.1527	37.8561	232.9186	1454.00000
6.2146	38.6214	240.0166	2637.00000

$$\ln p^* = a + b \ln T + c (\ln T)^2$$

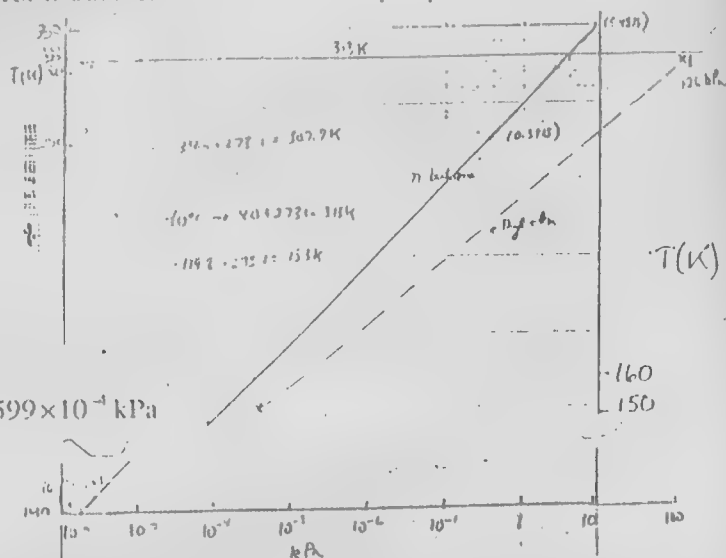
$$+ d (\ln T)^3$$

THE COEFFICIENTS ARE

1199.2548	a	-79.0261	c
532.2715	b	3.9638	d

4.73

(a) See Cox chart based on the data for n-butane. The estimated vapor pressure at 40°C



$$\frac{0.0027 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{101.3 \text{ kPa}}{1 \text{ atm}} \right| = 3.599 \times 10^{-4} \text{ kPa}$$

$$\frac{1 \text{ atm}}{1 \text{ atm}} \left| \frac{101.3 \text{ kPa}}{1 \text{ atm}} \right| = 101.3 \text{ kPa}$$

From the chart, the estimated vapor pressure at 307.7 K is **126 kPa**. The experimental value is 122.7 kPa.

(b) Fit the Antoine Eq.

$$\ln p = A - \frac{B}{C + T}$$

$$\ln(2.3) = A - \frac{B}{C + (-40 + 273)}$$

$$\ln(15.0) = A - \frac{B}{C + (-10 + 273)}$$

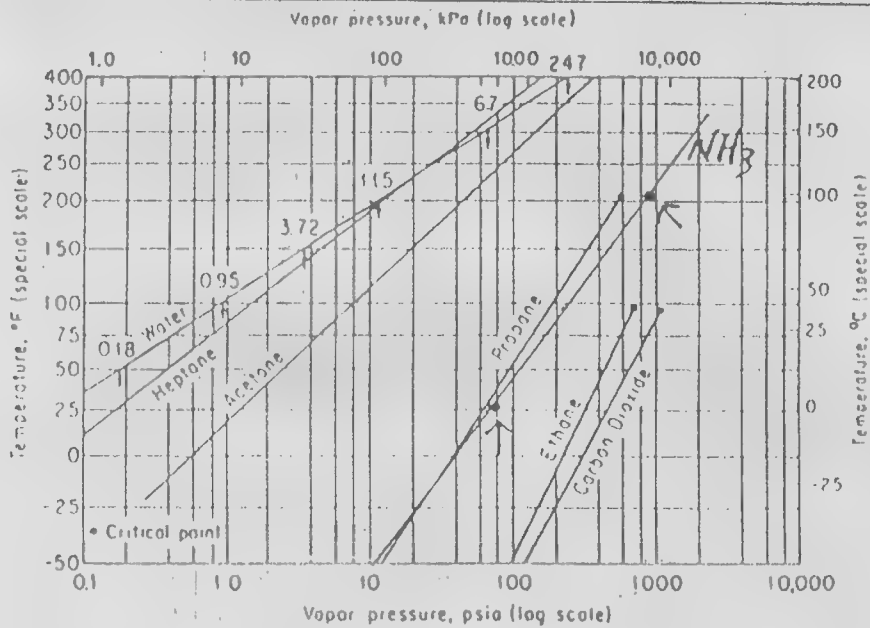
$$\ln(20.0) = A - \frac{B}{C + (20 + 273)}$$

solve to get A, B, and C
and then use the Antoine
Eq. to predict p at 40°C.

4.74

Prepare a Cox chart as described in the text. Use semi-log paper with the horizontal axis $\log_{10}$. Obtain vertical scale rules by use of steam properties at even integers for the temperature. Or you can use Antoine Equation, Appendix G, to get 2 points and draw a line between them.

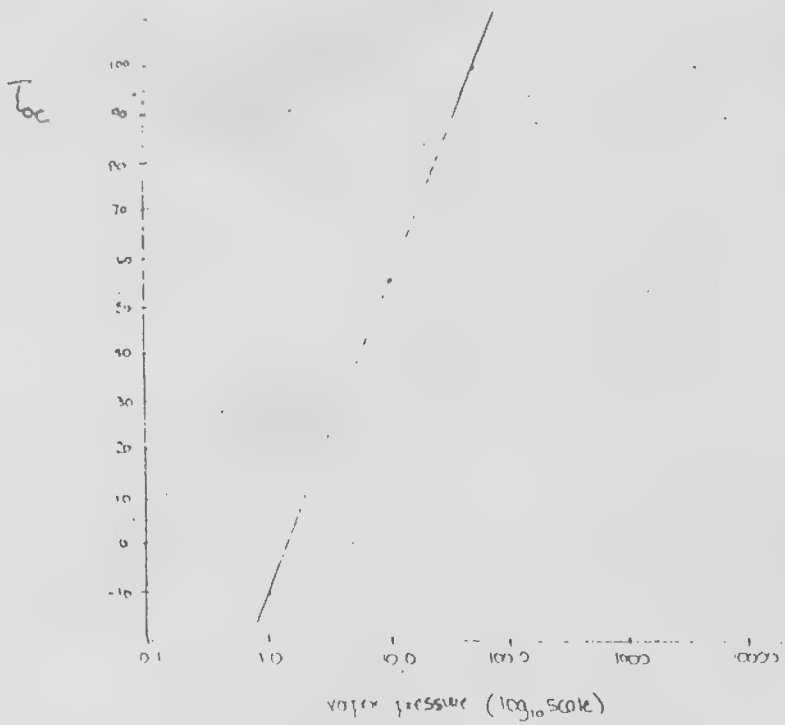
(continued)



4.75

Estimate vp of SO₂ at 100°C (373K); the actual vp = 29 atm.

t(°C)	-10	6.3	32.1	55.5
p*(atm)	1	2	5	10



(continued)

Read from this graph, the v.p. is close to $101.65 = \boxed{44 \text{ atm}}$

This procedure is really not accurate, as 44 seems relatively much larger than 29.

76


 27°C

$$p^* = 3.536 \text{ kPa}$$

dry N_2
 27°C

$$p = 101.3 \text{ kPa}$$

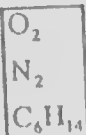
$$p_{\text{r}} = p_{\text{N}_2} + p_{\text{H}_2\text{O}} = (101.3 + 3.536) \text{ kPa} = \boxed{104.8 \text{ kPa}}$$

$$\text{b) } \frac{n_{\text{H}_2\text{O}}}{n_{\text{N}_2}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{N}_2}} = \frac{3.536 \text{ kPa}}{101.3 \text{ kPa}} = \boxed{0.0349}$$

4.77

 $T = -20^\circ\text{C}$

$$p^* = 141.1 \text{ mmHg}$$



$$p_{\text{t}} = 760 \text{ mmHg}$$

$$p_{\text{air}} = 760 - 14.1 = 745.9 \text{ mmHg}$$

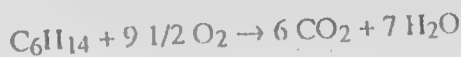
$$p_{\text{C}_6\text{H}_{14}} = p^*_{\text{C}_6\text{H}_{14}} = 14.1 \text{ mmHg}$$

Basis: 760 mol saturated gas

$p \Rightarrow \text{moles}$

O_2	$.21 (745.9)$	$= 156.6$
N_2	$.79 (745.9)$	$= 589.3$
C_6H_{14}		$= \frac{14.1}{760}$

For complete combustion



14.1 mol C_6H_{14} required $14.1 (9.5) = 134 \text{ mol O}_2$ required

$$156.6 - 134 = 22.60 \text{ mol O}_2 \text{ excess}$$

$$\frac{22.60}{134} \times 100 = \boxed{17 \%}$$

Solutions - Chapter - 4

4.78 mol. wt. $\text{CCl}_3\text{NO}_2 = 164.5$

Basis: 1 mol saturated gas

CCl_3NO_2	mol fr.
air	0.02
	0.98
	1.00

$$\frac{100 \text{ kPa}}{1 \text{ mol gas}} \left| \frac{0.02 \text{ mol } \text{CCl}_3\text{NO}_2}{101.3 \text{ kPa}} \right| \frac{760 \text{ mm Hg}}{101.3 \text{ kPa}} = 15.0 \text{ mm Hg}$$

(a) Using linear interpolation, which may introduce a slight error, 15.0 mm Hg corresponds to

$$\left(\frac{15.0 - 13.8}{20 - 15} \right) (5) = 1.5 + 15 = \boxed{16.5^\circ\text{C}}$$

(a) Basis: 100 m^3 at 100 kPa and 16.5°C

$$\frac{100 \text{ m}^3 \text{ air}}{101.3 \text{ kPa}} \left| \frac{100 \text{ kPa}}{289.5 \text{ K}} \right| \frac{273 \text{ K}}{22.4 \text{ m}^3 \text{ air at SC}} \left| \frac{1 \text{ kg mol air}}{22.4 \text{ m}^3 \text{ air at SC}} \right|$$

$$\frac{0.02 \text{ mol } \text{CCl}_3\text{NO}_2}{0.98 \text{ mol air}} \left| \frac{164.5 \text{ kg } \text{CCl}_3\text{NO}_2}{1 \text{ kg mol } \text{CCl}_3\text{NO}_2} \right| = \boxed{13.95 \text{ kg}}$$

4.79

(a) Volume increases

(b) Pressure increases

4.80

(a) $p_{\text{N}_2}^*$ exists if saturation occurs. Then, with $p_{\text{tot}} = 100 \text{ kPa}$

corresponds to

$$p_{\text{N}_2} = 100 (0.014) = 1.4 \text{ kPa which}$$

$$\boxed{-11.5^\circ\text{C}} \text{ from Perry}$$

or use Antoine Eqn. and solve for T ($p_{\text{N}_2}^* = 10.5 \text{ mm Hg}$)

$$\ln(10.5) = 15.9008 - \frac{2788.51}{T - 52.36}$$

b) Repeat for $p_{\text{N}_2}^* = 8.0 \text{ kPa}$ (60 mm Hg) corresponding to $\boxed{15.4^\circ\text{C}}$

4.81

$p_{H_2O}^*$ exists if the gas is saturated. $p_{H_2O}^*$ at $15^\circ\text{C} = 12.8 \text{ mm Hg}$ or 1.70 kPa . The total pressure would be $100 + 1.70 = \boxed{101.70 \text{ kPa}}$.

4.82

Basis: 1 lb air

If the air is saturated, $p_{C_8}^* = 2.36 \text{ in Hg}$ and $p_{\text{air}} = 29.66 - 2.36 = 27.30 \text{ in Hg}$.

$$\frac{p_{C_8}^*}{p_{\text{air}}} = \frac{2.36}{27.30} = 0.0864 \frac{\text{mol } C_8}{\text{mol air}}$$

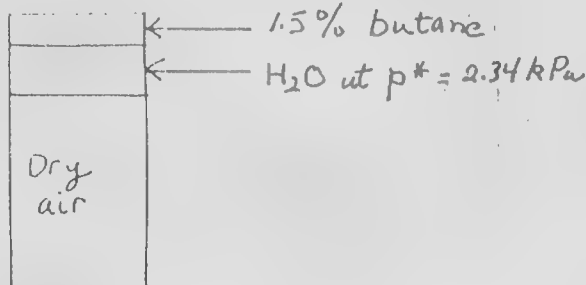
$$(a) \frac{\text{lb air}}{\text{lb } C_8} = \frac{27.30 \text{ mol Air}}{2.36 \text{ mol } C_8} \left| \frac{29 \text{ lb air}}{1 \text{ lb mol air}} \right| \frac{1 \text{ lb mol } C_8}{114.2 \text{ lb } C_8} = \boxed{2.94 \frac{\text{lb air}}{\text{lb } C_8}}$$

$$(b) \frac{2.36 \text{ mol } C_8}{(27.30 + 2.36) \text{ mol total}} = \frac{n_{C_8}}{n_{\text{tot}}} = \boxed{0.080} \text{ which is also the fraction of the volume.}$$

$$(c) \frac{2.94 \text{ lb air}}{\text{lb } C_8} \left| \frac{1 \text{ lb mol air}}{29 \text{ lb air}} \right| \frac{359 \text{ ft}^3 \text{ at SC}}{1 \text{ lb mol air}} \left| \frac{580^\circ\text{R}}{492^\circ\text{R}} \right| \frac{29.92 \text{ in Hg}}{29.66 \text{ in Hg}}$$

$$= \boxed{43.3 \text{ ft}^3} \text{ at } 120^\circ\text{F and } 29.6 \text{ in. Hg/lb octane}$$

4.83



$$p_t = p_{H_2O}^* + p_{C_4} + p_{\text{air}}$$

$$\text{or } n_t = n_{H_2O} + n_{\text{air}} + n_{C_4}$$

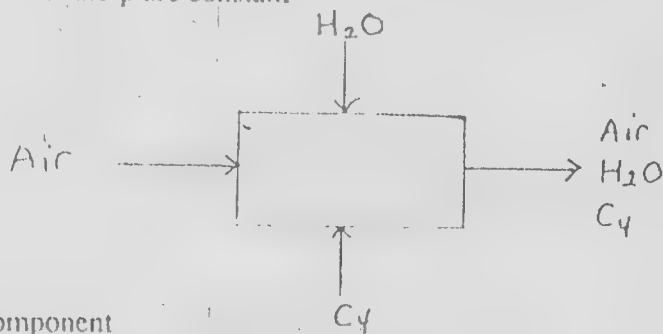
(in kPa)

$$p_t = 2.34 + 120 (0.015) + p_{\text{air}}$$

(continued)

$$p_{\text{air}} = 115.9 \text{ kPa}$$

$$\frac{p_{\text{air}}}{p_{\text{C}_4}} = \frac{n_{\text{air}}}{n_{\text{C}_4}} = \frac{V_{\text{air}}}{V_{\text{C}_4}} \text{ if } T \text{ and } p \text{ are constant}$$



C_4 is a tie component

Basis: 300 cm^3 (at 20.0°C and 100.0 kPa) or 1.0 min

$$n_{\text{C}_4} = \frac{pV}{RT} = \frac{100.0 \text{ kPa} \left| \frac{300 \text{ cm}^3}{293.15 \text{ K}} \left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^3 \right|}{8.314 (\text{kPa})(\text{m}^3)} \frac{(\text{kg mol})(\text{K})}{(\text{kg mol})(\text{K})}$$

$$= 1.231 \times 10^{-5} \text{ kg mol} = 1.231 \times 10^{-2} \text{ g mol C}_4$$

$$n_{\text{air}} = \frac{1.231 \times 10^{-2} \text{ g mol C}_4 \left| \frac{115.9 \text{ kPa air}}{1.80 \text{ kPa C}_4} \right|}{1.80 \text{ kPa C}_4} = 0.793 \text{ g mol}$$

$$V = \frac{nRT}{p} = \frac{0.793 \times 10^{-3} \text{ kg mol} \left| \frac{293.15 \text{ K}}{100 \text{ kPa}} \right| \frac{8.314 (\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}}{100 \text{ kPa}} = 1.93 \text{ m}^3$$

$$V = \boxed{1.93 \text{ m}^3} \text{ at } 100.0 \text{ kPa and } 20^\circ\text{C per min}$$

4.84

At equilibrium, the pressure of Hg is its vapor pressure

$$\frac{p_{\text{Hg}}}{p_{\text{t}}} = \frac{n_{\text{Hg}}}{n_{\text{t}}} = \frac{p_{\text{Hg}}^*}{p_{\text{air}}} = \frac{1.729 \times 10^{-4} \text{ g mol Hg}}{99.5 \text{ g mol air}}$$

Note: $p_{\text{t}} = p_{\text{air}} + p_{\text{Hg}} = p_{\text{air}}$ for all purposes so $\frac{1.729 \times 10^{-4} \text{ g mol Hg}}{99.5 \text{ g mol total gas}}$

Basis: $1.729 \times 10^{-4} \text{ g mol Hg}$

(continued)

$$29 \times 10^{-4} \text{ g mol Hg} \left| \frac{200.59 \text{ g}}{1 \text{ g mol Hg}} \right| \frac{1000 \text{ mg}}{1 \text{ g}} = 38.14 \text{ mg Hg}$$

$$\frac{nRT}{p} = \frac{99.5 \text{ g mol air}}{99.5 \text{ kPa}} \left| \frac{293.15 \text{ K}}{(\text{kg mol}) (\text{K})} \right| \frac{8.314 \text{ (kPa)(m}^3\text{)}}{1000 \text{ g}} = 2.44 \text{ m}^3 \text{ at } 20^\circ\text{C and } 99.5 \text{ kPa}$$

$$65 \frac{\text{mg}}{\text{m}^3} \text{ at } 20^\circ\text{C and } 99.5 \text{ kPa.}$$

level is not acceptable.

A mercury spill can be cleaned up reasonably effectively by dusting with sulfur, then vacuuming with a vacuum cleaner specifically designed for mercury pick-up, which prevents the escape of mercury vapor.

The instructor should point out to the student that the assumption of the "no ventilation" is a very good approximation unless the surface of the mercury is rather large or there is truly ventilation in the storeroom.

85

Assume equilibrium.

At 75°F, from the Antoine equation, the vapor pressure of benzene is 90 mm Hg. Assume the barometer is 760 mm Hg abs.

$$\frac{\text{mol Bz}}{\text{mol air}} = \frac{p_{\text{Bz}}}{p_{\text{t}} - p_{\text{Bz}}} = \frac{90}{760 - 90} = 0.13 \frac{\text{mol Bz}}{\text{mol air}}$$

a) The OSHA limit is 1 ppm over 8 hours. The above greatly exceeds this limit.

b) No, because the garage is probably not well ventilated, and also if a water heater is in the garage, the LEL (Lower Explosive Limit) may be exceeded.

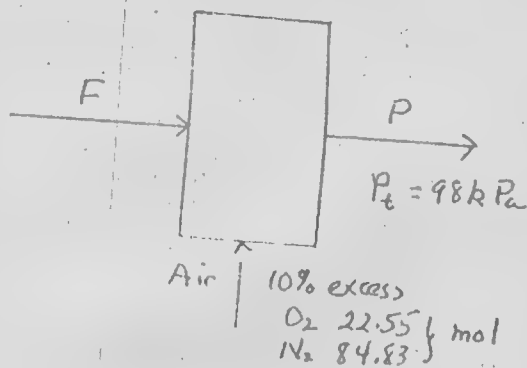
4.86

Steps: 1,2,3,4: Process is steady state with a reaction.

(continued)

Solutions - Chapter - 4

mol %	
4.5	CO ₂
26.0	CO
13.0	H ₂ O
0.5	CH ₄
56.0	N ₂
100.0	



n_{CO_2}
 n_{H_2O}
 n_{N_2}
 n_{O_2}

Step 4: Calculate the xs air and add moles to diagram

Step 5: Basis: 100 mol synthesis gas

Step 6: Unknowns: $n_{O_2}, n_{CO_2}, n_{H_2O}, n_{N_2}, P$

(5 total)

Step 7: Balance: C, O, H, N, $\Sigma n_i = P$

Step 8, 9: Use element balances

(5 independent equations)

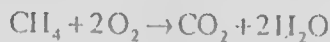
	in		out	
C:	4.5	+ 26.0 + 0.5	=	n_{CO_2}
H:	0.5 (4)	+ 13 (2)	=	$n_{H_2O} (2)$
O ₂ :	4.5	+ $\frac{26.0}{2}$ + 22.55	=	$n_{CO_2} + \frac{n_{H_2O}}{2}$
N ₂ :	56.0	+ 84.83	=	n_{N_2}
				$n_{CO_2} = 31.0$ $n_{H_2O} = \frac{28}{2}$ $n_{O_2} = 2.05$ $n_{N_2} = \frac{140.8}{187.9}$

$$x_{H_2O} = \frac{28}{202}$$

$$P_{H_2O} = 98 \left(\frac{14}{187.9} \right) = 7.3 \text{ kPa}$$

This is equivalent to a temperature of 104°F

7



$$\frac{0.8335 \text{ mol N}_2}{0.79 \text{ mol N}_2} \left| \frac{0.21 \text{ mol O}_2}{2 \text{ mol O}_2} \right| \frac{1 \text{ mol CO}_2}{2 \text{ mol O}_2} = 0.1108 \text{ mol CO}_2$$

$$0.8335 - 0.1108 = 0.0597 \text{ mol H}_2\text{O}; 0.0057 (20) = 1.114 \text{ psia}$$

Dew point $\approx$ 105 °F at 1.114 psia

At constant temperature of 130 °F, the gas must be compressed until the partial pressure ceases and becomes equal to the vapor pressure in order to reach the point of condensation.

From Steam tables, the vapor pressure of water at 130 °F is 2.223 psia.

The total pressure at which the partial pressure of water (mol fraction = 0.0557) will be 2.223 is

$$P_{H_2O} = P_i y_{H_2O}$$

$$\frac{2.223}{0.0557} = \text{40.1 psia}$$

$$\text{sum } \Sigma \frac{y_i}{LFL_i} = 1.0$$

if the mixture is at the flash point.

assuming Raoult's Law applies

$$y_i = \frac{p_i^* x_i}{p}$$

p_i^* = Vapor Pressure of i

p = Total Pressure

x_i = Liquid Phase Mole Fraction

y_i = Vapor Phase Mole Fraction

Assume $T = 65 \text{ °F}$

x_i	$p_i^* \text{ (Atm)}$	y_i	LFL
0.60	0.0123	0.00738	0.010
0.15	0.00365	0.000548	0.008
0.25	0.00116	0.000290	0.008

Data For
 p^* from
 Perry 6ed
 Table 3-8

(continued)

$$\sum \frac{y_i}{LFL_i} = 0.843$$

Assume $T = 70^\circ\text{F}$

C_1	0.60	0.0045	0.0057
C_2	0.15	0.0011	0.0015
C_{10}	0.25	0.00141	0.00185

$$\sum \frac{y_i}{LFL_i} = 0.997$$

Flash Point $\approx 70^\circ\text{F}$

4.89

Assume pentane is the major contributor to the gas-phase composition.

Note: $y_i = \frac{p_i}{p_{\text{tot}}}$

For Raoult's law,

$$p_i = p_i^* x_i$$

so

$$p_i^* = \frac{y_i p_{\text{tot}}}{x_i} = \frac{(0.018)(100)}{0.05} = 36 \text{ kPa}$$

Using the Antoine equation,

$$\ln(36) = 15.8333 - \frac{2477.07}{-39.94 + T}$$

$$T = 242 \text{ K}$$

90

Basis: 100 mol Vapor

Comp	Mole %	p_i^* @ 66°F (mm) Hg	$\frac{y_i}{p_i^*}$
Ethane	10	57,600	1.73×10^{-6}
Propane	25	17,000	14.7×10^{-6}
iso-butane	30	7,250	41.5×10^{-6}
n-butane	30	5,370	46.5×10^{-6}
iso-pentane	10	2,400	41.5×10^{-6}
	100		$\Sigma = 145.9 \times 10^{-6}$

$$= \frac{1}{\Sigma \frac{y_i}{p_i^*}} = \frac{1}{145.9 \times 10^{-6}} = 6880 \text{ mm Hg}$$

$$= x_i \frac{p_i^*}{p} : x_i = \frac{y_i p_i^*}{p}$$

$$= \frac{(0.1)(6880)}{(57,600)} = 0.012$$

$$= \frac{(0.25)(6880)}{(17,000)} = 0.102$$

$$= \frac{(0.30)(6880)}{(7,250)} = 0.284$$

$$= \frac{(0.25)(6880)}{(5370)} = 0.319$$

$$= \frac{(0.10)(6880)}{(2400)} = 0.286$$

Mole %
1.2
10.2
28.4
31.9
28.6
100.4

91

Basis: $p_{Nap}^* @ 180^\circ \text{F} = 460 \text{ mm Hg}$

$p_{H_2O}^* @ 180^\circ \text{F} = 388 \text{ mm Hg}$

$$P_{Max} = P_{H_2O} + P_{Naptha} = 460 + 388 = \boxed{848 \text{ mm Hg}} \quad (a)$$

$p_{Naptha}^* @ 160^\circ \text{F} = 318 \text{ mm Hg}$

(continued)

$$p_{H_2O} @ 100^\circ F = 245 \text{ mm Hg}$$

Basis: 6000 lb feed

$$(5000)(0.928) = 4640 \text{ lb pure Naptha}$$

$$\frac{\text{lb mol H}_2\text{O}}{\text{lb mol Nap}} = \frac{245}{318} = 0.77$$

$$\frac{W_1}{W_2} = \frac{n_1 M_1}{n_2 M_2}; W_1 = 4640 \left(\frac{18}{107} \right) (0.77) = 600 \text{ lb H}_2\text{O Distilled}$$

$$1000 - 600 = \boxed{400 \text{ lb H}_2\text{O left}} \quad (b)$$

4.92

Pressure at the bottom of the lake = P_{CO_2}

Avg. depth = 225 m

$$P_{CO_2} = \frac{1000 \text{ kg}}{\text{m}^3} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \frac{225 \text{ m}}{1} = 2.21 \times 10^3 \text{ kPa} + 1.01 \times 10^2 \text{ kPa}$$

$$= 23 \text{ atm}$$

$$P_{CO_2} = Hx_{CO_2} \Rightarrow x_{CO_2} = \frac{23 \text{ atm}}{1.7 \times 10^3 \frac{\text{atm}}{\text{mol fr}}} = 0.0134$$

$$\frac{200,000 \text{ ton H}_2\text{O}}{1} \left| \frac{1000 \text{ kg}}{\text{ton}} \right| \left| \frac{1 \text{ kg mol}}{18 \text{ kg}} \right| = 1.11 \times 10^7 \text{ kg mol}$$

$$0.0134 = \frac{n_{CO_2}}{1.11 \times 10^7 + n_{CO_2}} \quad n_{CO_2} \text{ is mol of CO}_2$$

$$n_{CO_2} = 1.51 \times 10^5 \text{ kg mol}$$

$$\frac{nRT}{p} = V_{CO_2} = \frac{(1.5 \times 10^5)(8.314)(273)}{101.3 \text{ kPa}} = \boxed{3.39 \times 10^6 \text{ m}^3}$$

4.93

Calculate the dewpoint assuming the mixture is ideal

$$1 = p_i \sum \frac{y_i}{p_i^*} \quad (a) \quad p_i = 200 \text{ psia and } y_i \text{ is given}$$

Either assume a sequence of temperatures that will enable you to calculate p_i^* that finally satisfy the above equation, or use Antoine's equation for p_i^* , and solve the resulting nonlinear equation on the computer.

$$p_i^* = \exp \left[A - \frac{B}{T+C} \right] \quad (b)$$

An alternate relation to use instead of (a) is

$$1 = \sum \frac{y_i}{K_i} \quad (c)$$

and the K_i can come from equations or charts

Using vapor pressure data, $T = 77^\circ\text{F}$. Using K values, $T = 75^\circ\text{F}$.

The liquid composition can be calculated from

$$\frac{y_i p_i}{p_i^*} = x_i$$

4.94

Assume an ideal solution. The total pressure is the sum of the vapor pressures of the liquid components. According to Raoult's Law, $p_i = p_i^* x_i$.

At 100°F

Component	x_i	p_i^* (mm Hg)	p_i (mm Hg)
i - C ₄	0.110	4000	440
i - C ₅	0.100	1000	100
n - C ₆	0.120	350	42
n - C ₇	0.070	75	5.25
> C ₇		ignore 5350	587 (continued)

$$\frac{587 \text{ mm Hg abs}}{760 \text{ mm Hg abs}} \left| \frac{14.696 \text{ psia}}{14.696 \text{ psia}} \right| = 11.35 \text{ psia}$$

The can was tested to $14.696 + 5.0 = 19.7 \text{ psia}$, so it should not leak

b) Repeat the above calculation for several temperatures until $\sum p_i = 19.7 \text{ psia}$ (1019 mm Hg abs)

$$T = 120^\circ\text{F}$$

4.95

For multiple components, the vapor pressure varies with composition as well as with temperature, and to be precise the composition should be stated.

4.96

Basis: 100 mol feed

	<u>f = mol</u>	<u>K</u>
1. water	15.0	5.26
2. DmA	70.0	0.64
3. Inert	15.0	

The flash equations can be reorganized to a function of L/V:

$$\left(\frac{L}{V}\right)^2 \left[\frac{100}{K_1 K_2} - \frac{f_1}{K_2} - \frac{f_2}{K_1} \right] + \frac{L}{V} \left[\frac{100}{K_2} + \frac{F}{K_1} - \frac{f_1}{K_2} - \frac{f_2}{K_1} - f_1 - f_2 \right] + 100 - f_1 - f_2 = 0$$

or solved directly as a quadratic equation. The solution is

<u>Comp.</u>	<u>Vapor Mol</u>	<u>Liquid Mol</u>
1	6.0	9.0
2	5.2	64.8
3		15.0
Total	11.2	88.8

4.97 The pressure in the condenser can be calculated from Raoult's law.

	mol. fr.	p^* (psia)	p_i (psia)
C ₃	0.738	188	139.00
C ₄	0.257	53	13.60
C ₅	0.005	16	0.08
			152.68

Next, calculate the composition and temperature on the top tray at 152.68 psia (a dew point calculation). Start with T higher than 100°F but not so high that you are out of range for equilibrium of vapor and liquid, say T = 120°F. A computer solution gives for the liquid composition:

C ₃	0.449	at 122°F
C ₄	0.519	
C ₅	0.032	
	1.000	

4.98 Calculate the bubble point and dew point temperatures at 19.34 in. Hg
 ≡ 1000 mm Hg. Use the Antoine equations to get p^* based on the assumption the solution is ideal.

$$\ln p^* = A - \frac{B}{C+T}$$

$$K_i = \frac{p_i^*}{p_i} \quad \ln K_i = \ln p_i^* - \ln p_i = \ln p_i^* - 6.9078$$

Calculate $\ln K_1$ and $\ln K_2$. Solve the bubble point equation and the dew point equation by a computer code (or Newton's method) starting with

$$T = 365 \text{ K (slightly above } p^* \text{ for benzene)}$$

$$(a) \quad f(T) = 0.5 K_1 + 0.5 K_2 - 1 = 0 \text{ where } K_i \text{ is a function of } T$$

$$(b) \quad f(T) = \frac{0.5}{K_1} + \frac{0.5}{K_2} - 1 = 0 \text{ where } K_i \text{ is a function of } T$$

Answers are: bubble-point temperature = 375.1 K

dew point temperature = 381.5 K

4.99

Use the flash vaporization relations given in the text to calculate the following:

(a)

$$V/F = 0.3 \quad T = 271.3^\circ\text{F}$$

	x	y
N-Hexane	.0632	.0192
N-Pentane	.2262	.1388
Iso-Pentane	.2191	.1555
N-Butane	.1869	.2307
Iso-Butane	.3046	.4559

(b)

$$V/F = 0.6 \quad T = 279.3^\circ\text{F}$$

	x	y
N-Hexane	0.0837	0.0275
N-Pentane	0.2520	0.1653
Iso-Pentane	0.2343	0.1772
N-Butane	0.1694	0.2204
Iso-Butane	0.2606	0.4096

100. The temperature range where the liquid and vapor can exist in equilibrium is between the bubble point and the dew point.

The solution is assumed to be ideal because it consists of hydrocarbons.

Vapor pressure data is taken from the 65th edition of the Handbook of Chemistry and Physics:

Component	760	1520	3800	7600	15200	30400	
propane	-42.1	-26.6	+1.4	26.9	58.1	94.8	Temp. ($^\circ\text{C}$)
isobutane	-11.7	+7.5	39.0	66.8	99.5	-	
n-butane	-0.5	+18.8	50.0	79.5	116.0	-	
isopentane	27.8	48.8	82.8	114.5	154.0	-	
neopentane	36.1	58.0	92.4	124.7	164.3	-	

Using the program "ANTOINE" on the computer disk and the above data; the Antoine equation coefficients can be found for the form

$$p_i^* = \log^{-1} \left(A - \frac{B}{C + T} \right) \quad \text{where } T \text{ is in } ^\circ\text{C}$$

(continued)

Component	mol %	x_i	Δ	B	C
propane	10	0.10	6.9813	879.80	265.91
i-butane	10	0.10	7.4962	1311.12	295.98
n-butane	40	0.40	6.6283	818.76	218.61
i-pentane	10	0.10	6.7514	964.42	221.36
n-pentane	30	0.30	6.8916	1069.77	230.54

$$p_t = \sum_{i=1}^5 p_i^* x_i \quad p_t = 100 \text{ psia} = 5170 \text{ mm Hg}$$

$$\begin{aligned}
 5170 \text{ mm Hg} = & \log^{-1} \left(6.9813 - \frac{879.80}{256.91 + T_B} \right) (0.10) + \log^{-1} \left(7.4962 - \frac{1311.12}{295.98 + T_B} \right) (0.10) \\
 & + \log^{-1} \left(6.6283 - \frac{818.76}{218.61 + T_B} \right) (0.40) + \log^{-1} \left(6.7514 - \frac{964.42}{221.36 + T_B} \right) (0.10) \\
 & + \log^{-1} \left(6.8916 - \frac{1069.77}{230.54 + T_B} \right) (0.30)
 \end{aligned}$$

The above equation can be solved using the program "NEWTON".

$$\text{Bubble point temperature} = T_B = 62.227^\circ\text{C}$$

The dew point temperature is calculated:

$$\frac{1}{p_t} = \sum_{i=1}^n \frac{y_i}{p_i^*}$$

$$\begin{aligned}
 \frac{1}{5170} = & \frac{0.10}{\log^{-1} \left(6.9813 - \frac{879.80}{256.91 + T_D} \right)} + \frac{0.10}{\log^{-1} \left(7.4962 - \frac{1311.12}{295.98 + T_D} \right)} \\
 & + \frac{0.40}{\log^{-1} \left(6.6283 - \frac{818.76}{218.61 + T_D} \right)} + \frac{0.10}{\log^{-1} \left(6.7514 - \frac{964.42}{221.36 + T_D} \right)} \\
 & + \frac{0.30}{\log^{-1} \left(6.8916 - \frac{1069.77}{230.54 + T_D} \right)}
 \end{aligned}$$

$$\text{Dew point temperature} = T_D = 81.696^\circ\text{C}$$

(continued)

Solutions - Chapter - 4

Therefore, the temperature range where the mixture can exist in vapor and liquid is between 62.2°C and 81.7°C

4.101

The following vapor pressure data is taken from the 65th edition of the Handbook of Chemistry and Physics:

Component	760	1520	3800	7600	15200	30400	
methane	-161.5	-152.3	-138.3	-124.8	-108.5	-80.3	Temp. (in °C)
ethane	-88.6	-75.0	-52.8	-32.0	-6.4	23.6	
propane	-42.1	-25.6	1.4	26.9	58.1	94.8	
i-butane	-11.7	7.5	39.0	66.8	99.5	-	
n-butane	0.5	18.8	50.0	79.5	116.0	-	
n-pentane	36.1	58.0	92.4	124.7	164.3	-	

Using the computer program "ANTOINE" on the computer disk and the above data; the Antoine equation coefficients can be found for the form

$$p^*_i = \exp \left(A - \frac{B}{C + T} \right) \quad \text{where } T \text{ is in } ^\circ\text{C}$$

Component	y_i	A	B	C
methane	0.01	6.0247	241.64	237.82
ethane	0.15	7.0038	731.35	266.16
propane	0.25	6.9813	879.80	256.91
i-butane	0.14	7.4962	1311.12	295.98
n-butane	0.25	6.6283	818.76	218.61
n-pentane	0.20	6.8916	1069.77	230.54

The minimum temperature at which the mixture can exist totally as a vapor is just above the dew point. The dew point is calculated as follows:

$$\frac{1}{p_t} = \sum_{i=1}^6 \frac{y_i}{p^*_i} \quad p_t = 100 \text{ psia} = 5170 \text{ mm Hg}$$

$$\frac{1}{5170} = \frac{0.01}{\log^{-1} \left(6.0247 - \frac{241.64}{237.82 + T_D} \right)} + \frac{0.15}{\log^{-1} \left(7.0038 - \frac{731.35}{266.16 - T_D} \right)}$$

(continued)

$$\begin{aligned}
 & + \frac{0.25}{\log^{-1}\left(6.9813 - \frac{879.80}{256.91 + T_D}\right)} + \frac{0.14}{\log^{-1}\left(7.4962 - \frac{1311.12}{295.98 + T_D}\right)} \\
 & + \frac{0.25}{\log^{-1}\left(6.6283 - \frac{818.76}{218.61 + T_D}\right)} + \frac{0.20}{\log^{-1}\left(6.8916 - \frac{1069.77}{230.54 + T_D}\right)}
 \end{aligned}$$

$$T_D = 63.9^\circ\text{C}$$

(b) Basis: 100 moles

$$90^\circ\text{F} = 32.2^\circ\text{C}$$

To find the mole % of vapor condensed, you can solve for L/F in the equation below; L/F is the fraction of liquid formed. The mole fraction of liquid is used in this equation; however, the given vapor mole fractions can be used here since the same state can be reached at 90°F starting with all vapor or all liquid.

K values below were taken from the Engineering Data Book of the Natural Gasoline Supply Men's Association, 1957:

Component i	K_i	ΔF_i
methane	19.0	0.01
ethane	5.2	0.15
propane	1.5	0.25
iso-butane	0.69	0.14
n-butane	0.51	0.25
n-pentane	0.18	0.20

$$1 = \sum_{i=1}^6 \frac{x_{F_i}}{1 - \frac{L}{F} \left(1 - \frac{1}{K_i}\right)}$$

$$\begin{aligned}
 1 = & \frac{0.01}{1 - \frac{L}{F} \left(1 - \frac{1}{19.0}\right)} + \frac{0.15}{1 - \frac{L}{F} \left(1 - \frac{1}{5.2}\right)} + \frac{0.25}{1 - \frac{L}{F} \left(1 - \frac{1}{1.5}\right)} \\
 & + \frac{0.14}{1 - \frac{L}{F} \left(1 - \frac{1}{0.69}\right)} + \frac{0.25}{1 - \frac{L}{F} \left(1 - \frac{1}{0.51}\right)} + \frac{0.20}{1 - \frac{L}{F} \left(1 - \frac{1}{0.18}\right)}
 \end{aligned}$$

This equation can be solved for L/F using the computer program "NEWTON".

(continued)

$$\frac{L}{F} = 0.69321$$

F is the basis of 100 moles, therefore,

$$L = (0.69321)(100) = 69.32 \text{ moles of liquid formed at } 32.2^\circ\text{C, i.e. } 69.32 \text{ mol \% of the vapor condensed.}$$

(c) Basis: 100 moles total

69.321 moles liquid

30.679 moles vapor

The composition of the liquid and vapor are found by doing material balances on each individual component:

$$Fy_{Fi} = Lx_i + Vy_i$$

F = total moles

L = moles of liquid

V = moles of vapor

$$y_i = K_i x_i$$

$$Fy_{Fi} = x_i (L + VK_i)$$

$$x_i = \frac{Fy_{Fi}}{L + VK_i}$$

This gives the liquid composition of component i. Then, substitute the answer for x_i into $y_i = K_i x_i$ to find y_i .

For example, for CH_4 :

$$x_{\text{CH}_4} = \frac{(100)(0.01)}{69.321 + (30.679)(19.0)} = 0.0015$$

$$y_{\text{CH}_4} = (0.0015)(19) = 0.0291$$

(continued)

Solutions - Chapter - 4

Component	y_i	z_i
methane	0.0291	0.0015
ethane	0.3408	0.0656
propane	0.3251	0.2168
iso - butane	0.1068	0.1547
n - butane	0.1501	0.2942
n - pentane	0.0481	0.2672

) $(0.0291)(30.679) = 0.89276$ moles CH_4 in vapor of 1 total mole

$= 89.28 \% \text{CH}_4$ in vapor

$(0.0481)(30.679) = 1.4757$ moles C_5H_{12} in vapor of 20 total moles

$= 7.38 \% \text{C}_5\text{H}_{12}$ in vapor

) 40 mole % condensed

$L/F = 0.40$

$$1 = \sum_{i=1}^6 \frac{x_{F_i}}{1 - \frac{L}{F} \left(1 - \frac{1}{K_i} \right)}$$

$$1 = \frac{0.10}{1 - 0.40 \left(1 - \frac{1}{K_{\text{CH}_4}} \right)} + \frac{0.15}{1 - 0.40 \left(1 - \frac{1}{K_{\text{C}_2\text{H}_6}} \right)} + \frac{0.25}{1 - 0.40 \left(1 - \frac{1}{K_{\text{C}_3\text{H}_8}} \right)}$$

$$+ \frac{0.14}{1 - 0.40 \left(1 - \frac{1}{K_{i-\text{C}_4}} \right)} + \frac{0.25}{1 - 0.40 \left(1 - \frac{1}{K_{n-\text{C}_4}} \right)} + \frac{0.20}{1 - 0.40 \left(1 - \frac{1}{K_{n-\text{C}_5}} \right)}$$

K_i is a function of temperature so this equation must be solved by trial and error, choosing a temperature and finding the values for K_i at that temperature.

The temperature must be somewhere between the dew point, 63.901°C , and 32.2°C where 9.588% was found to have condensed.

Trial	Temp. ($^\circ\text{C}$)	K_{CH_4}	$K_{\text{C}_2\text{H}_6}$	$K_{\text{C}_3\text{H}_8}$	$K_{i-\text{C}_4}$	$K_{n-\text{C}_4}$	$K_{n-\text{C}_5}$	Solution
1	45	20.0	6.00	1.80	0.92	0.61	0.220	0.9623
2	50	20.5	6.30	2.15	1.05	0.76	0.295	1.0272
3	48	20.3	6.25	2.10	0.98	0.72	0.275	1.0186
4	47	20.2	6.20	2.05	0.96	0.70	0.270	1.0035

(continued)

Solutions - Chapter - 4

47°C, 40 mole % of the vapor has condensed.

The point at which 100% of the vapor has condensed is the bubble point. This is calculated by

$$p_i = \sum_{i=1}^6 \log^{-1} \left(A - \frac{B}{C + T} \right) (x_i)$$

$$5170 = \log^{-1} \left(6.0247 - \frac{241.64}{237.82 + T_B} \right) (0.01) + \log^{-1} \left(7.0038 - \frac{731.35}{266.16 + T_B} \right) (0.15)$$

$$+ \log^{-1} \left(6.9813 - \frac{879.80}{256.91 + T_B} \right) (0.25) + \log^{-1} \left(7.4962 - \frac{1311.12}{295.98 + T_B} \right) (0.14)$$

$$+ \log^{-1} \left(6.6283 - \frac{818.76}{218.61 + T_B} \right) (0.25) + \log^{-1} \left(6.8916 - \frac{1069.77}{230.54 + T_B} \right) (0.20)$$

$$T_B = 1.31^\circ\text{C}$$

At 1.31°C, 100% of the vapor will have condensed

100,000 ft³ of gas

be assumed that the gas is ideal because of its hydrocarbon character.

$$n = \frac{pV}{RT} = \frac{(100 \text{ psia}) (100,000 \text{ ft}^3)}{(10.73 \text{ psia}) (\text{ft}^3) (\text{lb mole}) (^\circ\text{R}) (550^\circ\text{R})}$$

$$n = 1694 \text{ lb moles of gas}$$

$$69.321 \% \text{ condenses at } 90^\circ\text{F}$$

$$(1694) (0.69321) = 1174.29$$

the liquid composition from part c, the moles of each individual component can be found.

Component	x_i in liquid	lb mol	mol. wt.	lb
methane	0.0015	1.761	16.04	28.25
ethane	0.0656	77.034	30.07	2316
propane	0.2168	254.588	44.09	11220
n-butane	0.1547	181.664	58.12	10560
isobutane	0.2942	345.478	58.12	20080
pentane	0.2672	313.772	72.15	22640

(continued)

The following densities are taken from Perry's Handbook.

Component	lb	density (ft ³ /lb)	volume (ft ³)
methane	28.25	0.09877	2.790
ethane	2316	0.07550	174.9
propane	11220	0.03329	373.5
iso-butane	10560	0.02940	310.5
n-butane	20080	0.02822	566.7
n-pentane	22640	0.02544	576.0

Total volume = 2004.4 ft³

$$(2004.4 \text{ ft}^3) (7.481 \text{ gal/ft}^3) = 15,000$$

The pump will have to handle 15,000 gallons/minute.

102

$$F = C - P + 2 = 2 - 2 + 2 = 2$$

103 Ice point is lower than triple-point by 0.0095 C° due to fact that:

- (1) the pressure is 1 atm rather than V.P. of H₂O
- (2) air is dissolved in the H₂O

104 $F = C - P + 2$

$$(1) \quad F = 1 - 2 + 2 = 1$$

$$(2) \quad F = 2 - 3 + 2 = 1$$

$$(3) \quad C$$

H 3 Elements so $C = 3$

O

$$F = 3 - 1 + 2 = 4$$

105 (1) $F = C - P + 2$

(continued)

The rank of

	<u>CaCO₃(s)</u>	<u>CaO(s)</u>	<u>CO₂(g)</u>
Ca	1	1	0
C	1	0	1
O	3	1	2

$$\text{is only } 2 \quad \begin{bmatrix} 1 & 0 & 9 \\ 1 & 1 & 0 \\ 3 & 2 & 0 \end{bmatrix} \quad \text{so } C = 2$$

$$P = 3 \text{ hence } F = 2 - 3 + 2 = 1$$

4.106

Basis: gas as given in problem statement

$$(a) \quad 0.030 = \frac{P_{H_2O}}{P_{T\alpha} - P_{H_2O}} = \frac{P_{H_2O}}{101.8 - P_{H_2O}} \quad \text{so, } P_{H_2O} = 2.96 \text{ kPa}$$

$$P_{H_2O}^* \text{ at } 60^\circ\text{C} = 19.9 \text{ kPa}$$

$$\% \text{ humidity} = 100 \left(\frac{2.96}{19.9} \right) \left[\frac{101.6 - 19.9}{101.6 - 2.96} \right] = \boxed{12.2\%}$$

(b) Relative humidity

$$\frac{2.96}{19.9} = \boxed{14.9\%}$$

(c) Dewpoint occurs where $P_{H_2O}^* = 2.96 \text{ kPa}$, or $T = \boxed{24^\circ\text{C}}$ from the steam tables.

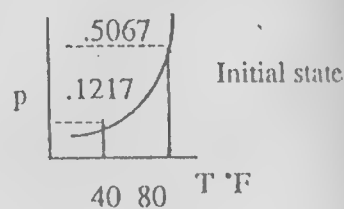
4.107

At 27°C , $P_{H_2O}^* = 3.52 \text{ kPa}$. The actual pressure of the water vapor is obtained from

$$p = \frac{nRT}{V} = \left(\frac{0.636}{18.01} \right) \left(\frac{8.314}{\text{m}^3} \right) \left(\frac{300\text{K}}{\text{K}} \right) \left(\frac{1}{28.0} \right) = 3.15 \text{ kPa}$$

$$100 \left(\frac{3.15}{3.52} \right) = \boxed{89\% \text{ RH}}$$

4.108



At 80 °F, $p_{H_2O}^* = 0.5067$ psia from the steam tables

At 40 °F, $p_{H_2O}^* = 0.1217$ psia

At 58 °F, $p_{H_2O}^* = 0.2384$ psia

$$(a) 100 \frac{0.1217 \text{ psia}}{0.5067 \text{ psia}} = \boxed{24\%}$$

(b) The mol fraction of H_2O vapor is constant on compression unless saturation is reached.
At the initial conditions

$$y_{H_2O} = \frac{0.1217}{14.696} = 8.28 \times 10^{-3}$$

$$\text{At 2 atm, } p_{H_2O} = p_{\text{Tot}} y_{H_2O} = (14.692)(2) \left(\frac{0.1217}{14.696} \right) = 0.2437 \text{ psia}$$

$$\frac{0.2437}{0.2384} > 1 \text{ hence water condenses and the}$$

relative humidity is 100%

4.109

$$T = 140^\circ\text{F}$$

$$p = 30 \text{ in Hg}$$



$$P_{H_2O}^* = 5.878 \text{ in Hg}$$

$$H = 0.03 \text{ mol } H_2O/\text{mol BDA} \Rightarrow \text{Basis: 1 mol BDA}$$

$$\frac{\text{mol } H_2O}{\text{mol } H_2O + \text{BDA}} = \frac{0.03}{1 + .03} = 0.0291 = y_{H_2O}$$

$$p_{H_2O} = 30 (.0291) = 0.874 \text{ in Hg}$$

$$p_{\text{air}} = 30 (1 - 0.0291) = 29.13 \text{ in Hg}$$

(continued)

$$(b) \% \text{ rel. humidity} = 100 \frac{P_{H_2O}}{P^*_{H_2O}} = 100 \left(\frac{0.874}{5.878} \right) = \boxed{14.9\%}$$

$$\% \text{ humidity} = \frac{\frac{P_{H_2O}}{P_T - P_{H_2O}}}{\frac{P^*_{H_2O}}{P_T - P^*_{H_2O}}} 100 = \frac{\frac{0.874}{30 - 0.874}}{\frac{5.878}{30 - 5.878}} 100$$

$$= \boxed{12.3\%}$$

(c) Dew point is the temperature at which vapor first condenses on cooling at constant humidity, hence $p^* = 0.874$ in Hg $\sim 75^\circ\text{F}$.

.110

From steam tables, $p^*_{w90^\circ\text{F}} = 0.6982$ psia. Assume constant pressure during the process.

Partial pressure of water, $p_w = (0.85) p^*_{w90^\circ\text{F}} = 0.593$ psia

Partial pressure of dry air, $p_{\text{dry air}} = \text{Total pressure} - p_w = 14.696 - 0.593 = 14.103$ psia

(d) Molal humidity

$$= \frac{\text{mol of water vapor}}{\text{mol of dry air}} = \frac{n_w}{n_{\text{dry air}}} = \frac{p_w}{p_{\text{dry air}}} = \frac{0.593}{14.103} = \boxed{0.042}$$

Humidity

$$= \frac{\text{lb of water vapor}}{\text{lb of dry air}} = \frac{0.042 \text{ lb mol H}_2\text{O}}{\text{lb mol dry air}} \left| \frac{18 \text{ lb H}_2\text{O/lb mol H}_2\text{O}}{29 \text{ lb air/lb mol air}} \right| = \boxed{0.026}$$

Percentage absolute humidity

$$= \frac{\text{actual molal humidity}}{\text{molal humidity at saturation}} = \frac{\frac{p_w}{(p_T - p_w)}}{\frac{p^*_{w90^\circ\text{F}}}{p_T - p^*_{w90^\circ\text{F}}}} = \frac{\frac{0.593}{14.103}}{\frac{0.698}{13.998}} = \boxed{0.843 \text{ or } 84.3 \text{ percent}}$$

Saturation temperature or the dew point is the temperature at which the vapor pressure of water will become equal to the existing partial pressure of 0.593 psia.

By interpolation dew point $\boxed{= 84.8^\circ\text{F}}$

(continued)

- (c) Number of degrees of superheat

$$= 90^{\circ}\text{F} - 85^{\circ}\text{F} = \boxed{5^{\circ}\text{F}}$$

- (f) At
- 105°F
- and
- 14.696
- psia, all the water is still present as vapor, i.e., the gas phase composition and hence the partial pressures are unchanged from those at
- 90°F
- . The molal humidity and dew point are the same as at
- 90°F
- .

- (g) At
- 60°F
- and
- 14.696
- psia, the air is cooled below its original dew point of
- 85°C
- . Hence, water will condense, and the resulting air will be saturated with water vapor.

$$\therefore \text{The dew point} = \boxed{60^{\circ}\text{F}}$$

To find the molal humidity, find the partial pressures:

$$p_w = p^*_{w_{60^{\circ}\text{F}}} = 0.2563 \text{ psia}$$

$$p_{\text{dry air}} = 14.696 - 0.256 \approx 14.44 \text{ psia}$$

Molar humidity

$$= \frac{n_w}{n_{\text{dry air}}} = \frac{p_w}{p_{\text{dry air}}} = \frac{0.2563}{14.44} = \boxed{0.0177 \text{ mol water / mol dry air}}$$

- (h) Water condensed:

Basis: 1.0 mol of dry air

$$\text{Initial water in air, at } 90^{\circ}\text{F, } 1 \text{ atm} = 0.042 \frac{\text{mol water}}{\text{mol dry air}}$$

$$\text{Final water in air, at } 60^{\circ}\text{F, } 1 \text{ atm} = 0.0177 \frac{\text{mol water}}{\text{mol dry air}}$$

$$\text{Water condensed} = 0.042 - 0.0177 = 0.0243 \frac{\text{mol water}}{\text{mol dry air}}$$

$$\text{Fraction of the original water condensed} = \frac{0.0243}{0.042} = \boxed{0.58}$$

4.111

$$T = 25^{\circ}\text{C}, p_{\text{Bz}} = 2.20 \text{ mm Hg}, p_t = 800 \text{ mm Hg, hence } p_{\text{air}} = 797.8 \text{ mm Hg}$$

(continued)

Solutions - Chapter - 4

$$(a) \frac{n_{Bz}}{n_t} = \frac{p_{Bz}}{p_t} \therefore \frac{n_{Bz}}{n_t} = \frac{2.20}{800} = \boxed{2.75 \times 10^{-3} \text{ mol Bz / mol gas}}$$

$$(b) \frac{n_{Bz}}{n_t - n_B} = \frac{p_{Bz}}{p_t - p_B} \therefore \frac{n_{Bz}}{n_{air}} = \frac{2.20}{797.8} = \boxed{2.7576 \times 10^{-3} \text{ mol Bz / mol Bz free gas}}$$

$$(c) \frac{\text{g Bz}}{\text{g Bz free gas}} = \frac{2.7576 \times 10^{-3} \text{ mol Bz}}{1 \text{ mol air}} \left| \frac{78 \text{ g Bz}}{1 \text{ g mol Bz}} \right| \left| \frac{1 \text{ g mol air}}{29 \text{ g air}} \right| = \boxed{0.0074}$$

$$(d) \text{Relative Saturation} = \frac{p_{Bz}}{p^*_{Bz} \text{ at } 25^\circ\text{C}}$$

$$p^*_{Bz} \text{ at } 25^\circ\text{C} = 95.6 \text{ mm Hg} \therefore \text{Rel. Saturation} = \frac{2.20}{95.6} = \boxed{0.023}$$

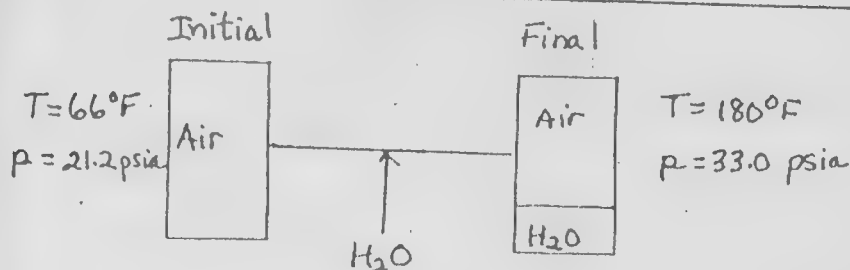
$$(e) \% \text{ Saturation} = (100) \frac{p_{Bz} / (p_t - p_{Bz})}{p^*_{Bz} / (p_t - p^*_{Bz})} = \frac{2.20 (800 - 95.6)}{95.6 (800 - 2.20)} = \boxed{20.4}$$

$$(f) \frac{\mu\text{g Bz}}{\text{m}^3} = \frac{2.20 \text{ g mol Bz}}{800 \text{ g mol gas}} \left| \frac{78 \text{ g Bz}}{1 \text{ g mol Bz}} \right| \left| \frac{10^6 \mu\text{g}}{1 \text{ g}} \right| \left| \frac{1 \text{ g mol gas}}{22.4 \text{ L at SC}} \right|$$

$$\left| \frac{1 \text{ L}}{1000 \text{ cm}^3} \right| \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \left| \frac{760 \text{ mm Hg}}{800 \text{ mm Hg}} \right| \left| \frac{298 \text{ K}}{273 \text{ K}} \right| = \boxed{9.96 \times 10^6 \text{ mg / m}^3 \text{ Exceeds the standard}}$$

$$(g) \frac{\text{g Bz}}{\text{ft}^3} = \frac{9.96 \times 10^6 \mu\text{g}}{\text{m}^3} \left| \frac{1 \text{ g}}{10^6 \mu\text{g}} \right| \left| \frac{0.028 \text{ m}^3}{1 \text{ ft}^3} \right| = \boxed{0.278 \text{ g Bz / ft}^3}$$

4.112



Basis: Air at $T = 66^\circ\text{F}$ and 21.2 psia ; assume V is constant.

(continued)

(a) Initial

$$P_{\text{air},i} V = n_{\text{air}} RT_{66^\circ\text{F}}$$

Final

Assume all of the water evaporates, and check later on to see if the assumption is true.

$$P_{\text{air},f} + P_{\text{H}_2\text{O}} = P_t \text{ so } P_{\text{air},f} = P_t - P_{\text{H}_2\text{O}}$$

$$P_{\text{air},f} V = n_{\text{air}} RT_{180^\circ\text{F}}$$

The material balance is simple: all the initial air = final air.

$$\frac{P_{\text{air},i}}{P_t - P_{\text{H}_2\text{O}}} = \frac{66 + 460}{180 + 460} = \frac{526}{640} = \frac{21.2}{33.0 - P_{\text{H}_2\text{O}}}$$

$$P_{\text{H}_2\text{O}} = 7.20 \text{ psia}$$

Since $p^* = 7.51$ psia, all of the water can evaporate and the air will not be saturated.(b) Basis: 1 lb H_2O (0.0555 lb mol H_2O)

At the final condition

$$\frac{P_{\text{H}_2\text{O}}}{P_t} = \frac{7.20}{33.0} = \frac{n_{\text{H}_2\text{O}}}{n_t} = \frac{0.0555}{n_t} \text{ so } n = 0.254 \text{ lb mol}$$

$$V = \frac{nRT}{p} = \left(\frac{0.254}{33.0} \right) \left(\frac{10.73}{33.0} \right) \left(\frac{640}{1} \right) = \boxed{53.0 \text{ ft}^3}$$

$$(c) \ n_{\text{air}} = 0.254 - 0.0555 = 0.1985 \text{ lb mol} \quad \frac{1 \text{ lb H}_2\text{O}}{0.1985(29)} = \boxed{\frac{0.17 \text{ lb H}_2\text{O}}{\text{lb air}}}$$

4.113

The vapor pressure of ethyl acetate at 30°C is 119 mm Hg.

$$\% \text{ relative saturation} = 50 = \frac{P_{\text{EAc}}}{P_{\text{EAc}}^*} (100)$$

$$P_{\text{EAc}} = 0.50 (119) = 59.5 \text{ mm Hg}$$

(continued)

$$(a) \frac{n_{\text{EtAc}}}{n_t} = \frac{p_{\text{EtAc}}}{p_t} = \frac{59.5}{740} = 0.0805$$

Hence the vapor analyzes 8.05% EtAc and 91.95% air.

(b) Molal saturation is

$$\frac{n_{\text{EtAc}}}{n_{\text{air}}} = \frac{p_{\text{EtAc}}}{p_{\text{air}}} = \frac{p_{\text{EtAc}}}{p_t - p_{\text{EtAc}}} = \frac{59.5}{740 - 59.5}$$

$$= \boxed{0.0876 \frac{\text{mol EtAc}}{\text{mol air}}}$$

4.114

Basis: 0.083 lb mol H_2O vapor/lb mol CH_4

a) $p_{\text{H}_2\text{O}}^*$ at 80 °F = 26 mm Hg (steam tables)

$$\frac{p_{\text{H}_2\text{O}}}{p_{\text{total}}} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{total}}}$$

$$\frac{0.0083}{1.0083} \frac{1520}{1} = \boxed{12.5 \text{ mmHg} = p_{\text{H}_2\text{O}}}$$

$$b) \% \text{ sat'n} = \left(\frac{\frac{12.5}{1520 - 12.5}}{\frac{26}{152 - 26}} \right) 100 = \boxed{47.7\%}$$

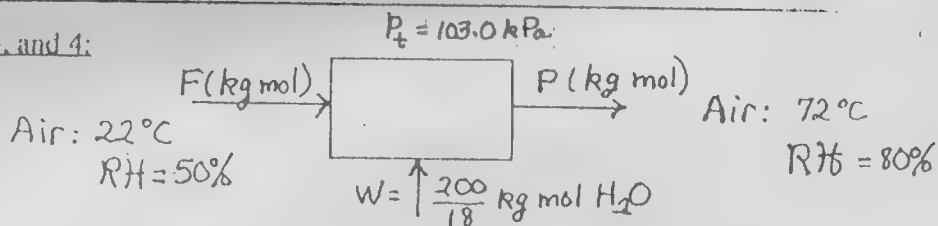
$$c) \frac{p_{\text{H}_2\text{O}}}{p_{\text{H}_2\text{O}}^*} = \frac{12.5}{26} = 0.20$$

When $p_{\text{H}_2\text{O}}^* = 62.5 \text{ mm Hg}$, the temperature is 109 °F

4.115

(continued)

Steps 1, 2, 3, and 4:

Data for p^*
from the steam tables:

$T (^\circ\text{C})$	$p^* (\text{kPa})$
$22^\circ\text{C} (295\text{K})$	2.622
$72^\circ\text{C} (345\text{K})$	33.77

These calculations provide the composition of F and P.

In		kPa	Out		kPa
$p_{\text{H}_2\text{O}} = 0.50 (2.60)$	=	1.31	$p_{\text{H}_2\text{O}} = 0.80 (33.77)$	=	27.02
$p_{\text{air}} = 103.0 - 1.31$	=	101.69	$p_{\text{air}} = 102.0 - 27.0$	=	76.0
P_t	=	103.0	P_t	=	103.0

Step 5: Basis: $W = 200 \text{ kg H}_2\text{O} (1 \text{ hour})$ Steps 6 and 7: Unknowns are: F, P Balances are: H_2O , air

Steps 8 and 9: This is a steady state process without a reaction

Balances	In	Out
H_2O	$F(1.3\%) + 200\% (1.00) = P(27.0\%)$	
air:	$F(101.7\%)$	$= P(76\%)$

 $F = 32.86 \text{ kg mol}$ $P = 43.95 \text{ kg mol}$

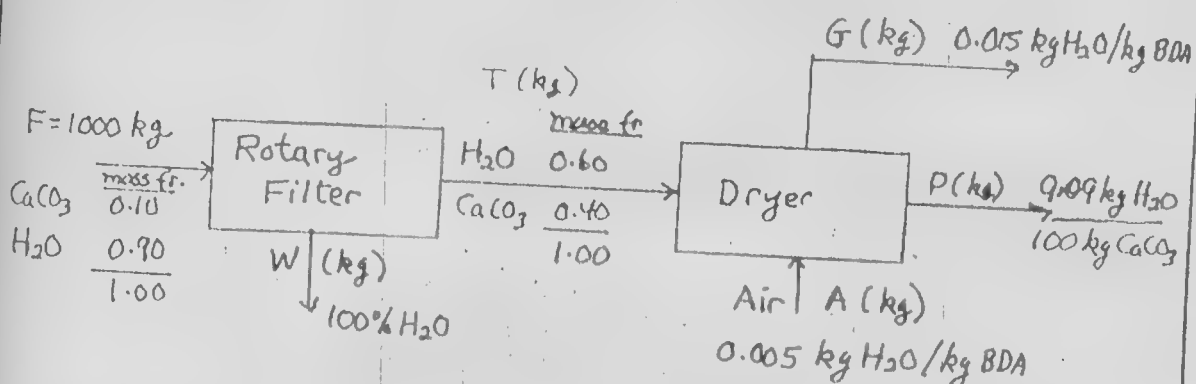
Bone dry air:

 $F(1.07\%) = 32.45 \text{ kg mol}$ $P(7\%) = 32.43 \text{ kg mol}$

Step 10: Check using total balance

4.116

Steps 1, 2, 3, and 4: This is a steady state process without reaction.



Calculate the composition of G , P , A in terms of mass fractions

G 0.015 kg H_2O
 1.000 kg air
 1.015 kg total

mass fr.

P 9.09 kg H_2O
 100.00 kg CaCO_3
 109.00 kg total

A 0.005 kg H_2O
 1.000 kg air
 1.005 kg to total

Step 5: System is the filter. Basis: $F = 1000 \text{ kg}$.

Step 6: Unknowns: T , W

Steps 7, 8, and 9:

	In		Out
CaCO_3 balance:	1000 (0.10)	=	T (0.40)
H_2O	1000 (0.90)	=	T (0.40) + W (1.00)
Total	1000	=	$T + W$

The balances are independent.

(continued)

All we need is the CaCO_3 balance as CaCO_3 is a tie component.

a. $T = 250 \text{ kg}$

$W = 1000 - 250 = \boxed{750 \text{ kg}}$

b. System is the dryer; same basis.

Step 6: The unknowns are G, P, and A

Steps 7, 8, and 9: We have 3 balances: H_2O , air, CaCO_3

	In		Out
CaCO_3 :	250 (.40)	=	P (100/109.09)
	$P = 109.09 \text{ kg}$		

(From an overall system balance on CaCO_3 with 100 kg CaCO_3 in and out in P the water out in P = 9.09 kg.)

air: $A \left(\frac{1.000}{1.005} \right) = G \left(\frac{1.000}{1.015} \right)$

H_2O : $250(.60) + A \left(\frac{0.005}{1.005} \right) = G \left(\frac{0.015}{1.015} \right) + P \left(\frac{9.09}{109.09} \right)$

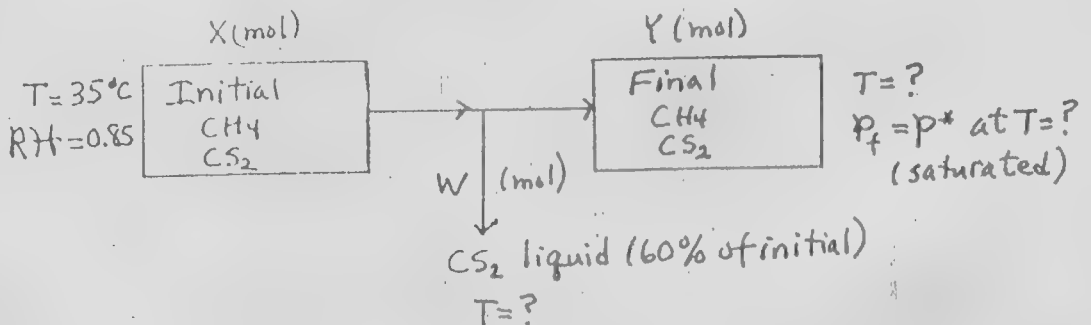
$A = \boxed{14,400 \text{ kg}}$

4.117

We will treat this problem as an unsteady state problem without reaction.

Steps 1, 2, 3 and 4:

$p^* = 15.4T + 130$



(continued)

Initial

$$\text{At } 35^\circ\text{C}, p^* = (15.4) 35 + 130 = 669 \text{ mm Hg}$$

$$p_{\text{CS}_2} = 669(0.85) = \frac{\text{mm Hg}}{569} \quad \frac{\text{mol fr.}}{0.76}$$

$$p_{\text{CH}_4} = 750 - 569 = \frac{181}{750} \quad \frac{0.24}{1.00}$$

Final

$$T = 7^\circ\text{C}, p^* \text{ is obtained from the vapor pressure equation}$$

$$\text{Step 5: Basis: } X = 1 \text{ mol} \quad (\text{Then } W = 0.60 \text{ mol})$$

$$\text{Step 6: Unknowns: } Y, T, p^*$$

$$\text{Step 7: Equations: CH}_4 \text{ and CS}_2 \text{ balances plus } p^* \text{ equation}$$

Steps 8 and 9:

Accumulation					
	Final		Initial	In	Out
CH ₄	$Y \left(\frac{750 - p^*}{750} \right)$	-	1.00 (0.24)	= 0	0
CS ₂	$Y \left(\frac{p^*}{750} \right)$	-	1.00(0.76)	= 0	0.60
Total	Y	-	1.00	= 0	0.60
	Y = 0.40				
	p* = 300 mm Hg				
	T = $\frac{p^* - 130}{15.4}$	=			3.7°C

4.118

Steps 1, 2, 2, 4:
toluene at

From tables, a data base, or the Antoine Eq., get the vapor pressure of

38 °C: 7.2 kPa

4 °C: 1.15 kPa

Let p be the pressure of the toluene

at 38 °C: $\frac{p}{p^*} \left(\frac{p_{\text{tot}} - p^*}{p_{\text{tot}} - p} \right) = 0.501$

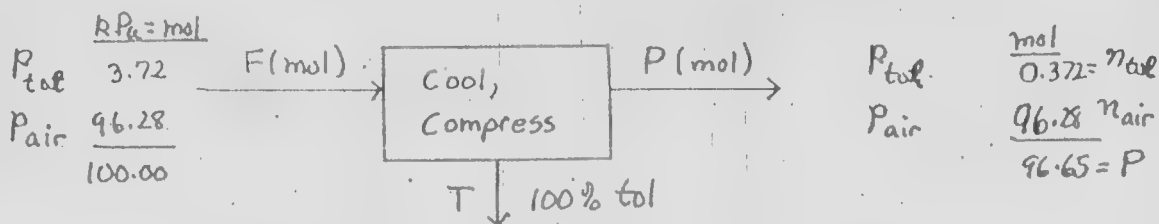
so that $p = 3.72$ kPa

$p_{\text{air}} = 100 - 3.72 = 96.28$ kPa

at 4 °C: The air is saturated with toluene

$p^* = 1.2$ kPa

$p_{\text{tot}} = ?$



Step 5:

Basis: $100 \text{ mol} = F$

Step 6 and 7: Two balances can be made, toluene and air
Two unknowns exist

$T = 0.90 (3.72) = 3.335$ mol

$3.72 - 3.35 = 0.372$

Steps 7, 8, and 9:

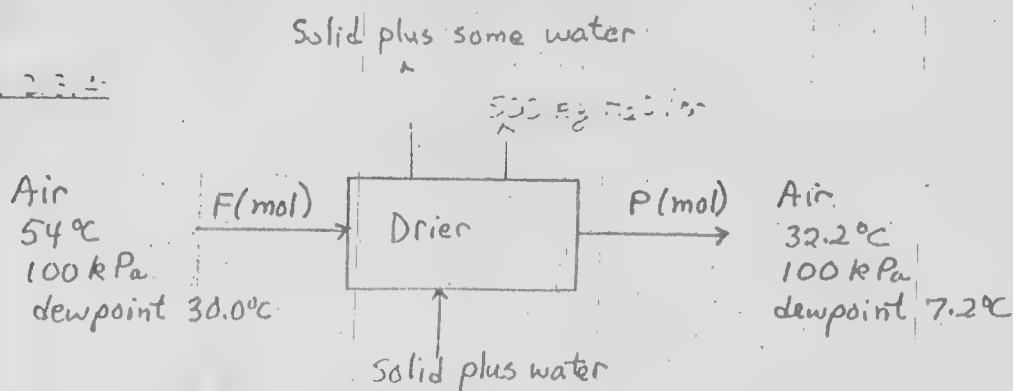
$$\text{Balances} \begin{cases} \text{air } 96.28 = n_{\text{air}} \\ \text{Toulene } 3.72 = 3.35 + 0.372 \end{cases}$$

$P = 96.65$

$p_{\text{tot}} \left(\frac{0.372}{96.65} \right) = p_{\text{tol}} = 1.15$

$p_{\text{tot}} = 298$ kPa

4.119

Steps 1, 2, 3, 4:

$$p_{\text{H}_2\text{O}} (30^\circ\text{C}) = 0.6153 \text{ psia} \\ = 4.25 \text{ kPa}$$

$$p_{\text{air}} = 100 - 4.25 = 95.75 \text{ kPa}$$

$$p^* (7.2^\circ\text{C}) = 0.1476 \text{ psia} \\ = 1.02 \text{ kPa}$$

$$p_{\text{air}} = 100 - 1.02 = 98.98 \text{ kPa}$$

Step 5: Basis: 500 kg H₂O/hr

Steps 6 and 7: Unknowns: F and P

Balances: air and H₂O

Steps 8 and 9: Balances in kg mol

$$\left. \begin{array}{l} \text{Total: } F - \frac{500}{18} = P \\ \text{Air: } F \left(\frac{95.75}{100} \right) = P \left(\frac{98.98}{100} \right) \\ \text{H}_2\text{O: } F \left(\frac{4.25}{100} \right) - \frac{500}{18} = P \left(\frac{1.02}{100} \right) \end{array} \right\} \begin{array}{l} \text{Use any two to get} \\ F = 851 \text{ kg mol} \end{array}$$

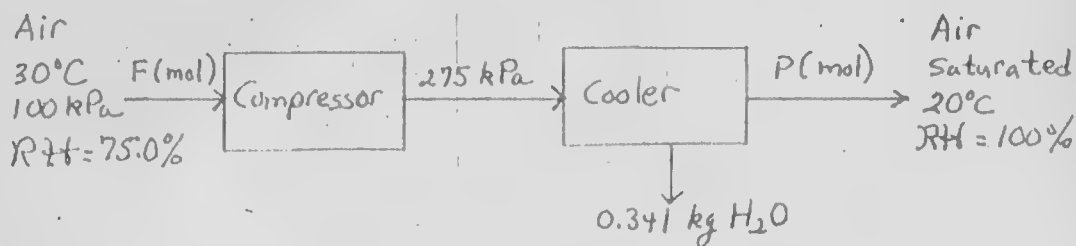
If the process was treated as an unsteady state one, the total balance would be accum = in - out,

$$\text{or } \frac{500}{18} = F - P.$$

$$V = \frac{851 \text{ kg mol}}{(\text{kg mol}) (\text{K})} \left| \frac{8.314 (\text{kPa}) (\text{m}^3)}{(\text{kg mol}) (\text{K})} \right| \frac{327 \text{ K}}{100 \text{ kPa}} = 2.31 \times 10^4 \text{ m}^3 \text{ at } 100 \text{ kPa and } 30^\circ\text{C}$$

4.120

Steps 1, 2, 3, and 4:



$$P_{H_2O} = 0.6153 \text{ psia}$$

$$= 4.241 \text{ kPa}$$

$$P_{H_2O} = 0.3388 \text{ psia}$$

$$= 2.34 \text{ kPa}$$

$$P_{H_2O} = 4.241 (0.75) = 3.18 \text{ kPa}$$

Step 5: Basis: 0.341 kg H₂OStep 6 and 7: Unknowns: F, P Balances: air, H₂O

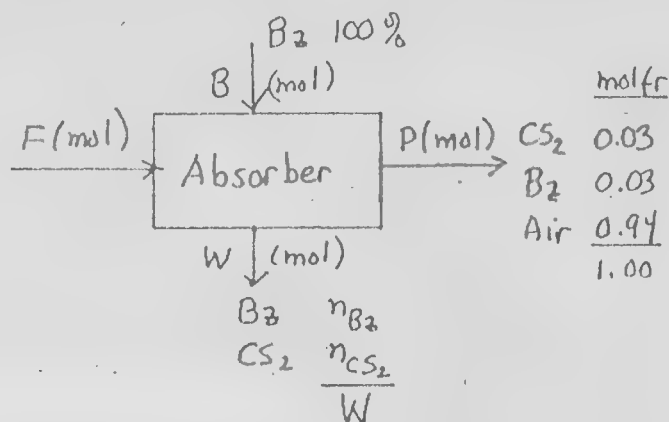
Steps 8 and 9: Balances are in kg mol

$$\left. \begin{aligned} \text{Total: } F &= P + \frac{0.341}{18} \\ \text{Air: } F \left(\frac{100 - 3.18}{100} \right) &= P \left(\frac{275 - 2.34}{275} \right) \\ \text{H}_2\text{O: } F \left(\frac{3.18}{100} \right) &= \frac{0.341}{18} + P \left(\frac{2.34}{275} \right) \end{aligned} \right\} \begin{array}{l} \text{Solve any two to get} \\ F = 0.804 \text{ kg mol} \end{array}$$

$$V = \frac{0.804 \text{ kg mol} \left| \frac{8.314}{100} \right| 303}{100} = 20.3 \text{ m}^3 \text{ at } 30^\circ\text{C and } 100 \text{ kPa}$$

4.121

Steps 1, 2, 3, and 4:



Step 5:

Basis: P: 100 mol

Steps 6 and 7:

Unknowns are F, B, n_{Bz} , n_{CS_2} Balances are CS_2 , Bz, Air

Steps 8 and 9:

$$\text{CS}_2: \quad F(0.12) = n_{\text{CS}_2} + 100(0.03)$$

$$\text{Bz:} \quad B = n_{\text{Bz}} + 100(0.03)$$

$$\text{Air:} \quad F(0.88) = 100(0.94)$$

$$F = 106.8 \text{ mol} \quad n_{\text{CS}_2} = 9.82 \text{ mol}$$

$$\text{Fraction CS}_2 \text{ recovered} = \frac{9.82}{12.82} = \boxed{0.77}$$

4.122

During the day, the vapor space is saturated and expands so that the air-hydrocarbon mixture escapes through the vent. At night, the gas mixture contracts, and fresh air enters so that more liquid will vaporize.

The volume change due just to the temperature change is

$$\frac{dV_t}{V_0} = \frac{dT}{T} \quad \text{using the ideal gas law}$$

where V_0 is the volume of the free space. As T increases, the vapor pressure of the octane increases. The volume change due to the vaporization is

$$\frac{dV_v}{V_0} = dy = \frac{dp^*}{P_t}$$

(continued)

where y is the mole fraction of octane in the vapor space, p^* is the vapor pressure of the octane, and p_i is the total pressure in the vapor space.

Thus, the total volume change is approximately

$$\frac{dV}{V_0} = \left(\frac{dT}{T} + \frac{dp^*}{p_i} \right)$$

Introduce $pV = nRT$ to get

$$dn = \frac{V_0 p^* dT}{RT^2} + \frac{V_0 p^* dp^*}{p_i RT}$$

Introduce the equation

$$\ln(p^*) = A - \frac{B}{T}$$

to get

$$dn = \frac{V_0 e^{[A - (B/T)]} dT}{RT^2} + \frac{V_0 p dp^* [A - \ln p^*] dp^*}{RB p_i}$$

Integrate between T_1 and T_2 to get N , the octane in lost in a day

$$N = \left(\frac{V_0}{RB} \right) \left\{ \left[\exp[A - (B/T_2)] - \exp[A - (B/T_1)] \right] + \frac{A}{2p_i} [p_2^* - p_1^*] - \frac{1}{p_i} \left[p_2^* \frac{\ln p_1^*}{2} - \frac{1}{4} \right] - p_1^* \left(\frac{\ln p_1^*}{2} - \frac{1}{4} \right) \right\}$$

For octane $p_i = 44$ mm Hg abs, $p_2 = 222$ mm Hg.

$$A = 7.30, \quad B = 1,600$$

$$\text{If } V_0 = 1 \text{ m}^3, \quad \boxed{N = 3.40 \text{ mol for 1 day.}}$$

4.123

(a)

Entering

$$80^{\circ}\text{F} = 26.8^{\circ}\text{C}$$

$$p^* \text{ at } 26.8^{\circ}\text{C} = 26 \text{ mm Hg}$$

$$\text{Rel. Humidity} = \frac{p}{p^*} = \frac{5 \text{ mm Hg}}{26 \text{ mm Hg}} (100)$$

$$= 19.2\%$$

Leaving

$$70^{\circ}\text{F} = 21.0^{\circ}\text{C}$$

$$p^* \text{ at } 21.0^{\circ}\text{C} = 19 \text{ mm Hg}$$

$$\text{Rel. Humidity} = \frac{p}{p^*} = \frac{18 \text{ mm Hg}}{19 \text{ mm Hg}} (100)$$

$$= 94.8\%$$

(b)

Entering

$$\text{Vol fr.} = \frac{V}{V_{\text{tot}}} = \frac{p}{P_{\text{tot}}}$$

$$\text{H}_2\text{O}: \frac{5 \text{ mm Hg}}{740 \text{ mm Hg}} (100) = 0.676\%$$

$$\text{Air}: 100 - 0.676 = 99.324\%$$

Leaving

$$\text{Vol fr.} = \frac{p}{P_{\text{tot}}}$$

$$\text{H}_2\text{O}: \frac{18 \text{ mm Hg}}{740 \text{ mm Hg}} (100) = 2.43\%$$

$$\text{Air}: 100 - 2.43 = 97.57\%$$

(c)

Entering

Basis: 1 lb mol at 80°F, 740 mm Hg
Vol % = mol %

	lb	wt %
H ₂ O: (0.00676)(18):	0.12	0.4
Air: (99.324)(29)	28.80	99.6
	28.92	100.0

Leaving

Basis: 1 lb mol at 70°F, 740 mm Hg

	lb	wt %
H ₂ O: (0.0243)(18)	0.44	1.53
Air: (0.9757)(29)	28.30	98.47
	28.74	100.00

(d)

Entering

Basis: 1 lb mol at 80°F, 740 mm Hg

Actual: $p_{\text{vap}} = 5 \text{ mm Hg}$ $p_{\text{vapor-free gas}} = 740 - 5 = 735 \text{ mm Hg}$ Saturated: $p_{\text{vap}} = 26 \text{ mm Hg}$ $p_{\text{vapor-free air}} = 740 - 26 = 714 \text{ mm Hg}$

$$\% \text{ Humidity} = \frac{\left(\frac{p_{\text{vap}}}{p_{\text{vapor-free air}} \text{ actual}} \right)}{\left(\frac{p_{\text{vap}}}{p_{\text{vapor-free air}} \text{ sat'd}} \right)} (100)$$

$$= \frac{\frac{5}{735}}{\frac{26}{714}} (100) = 18.9\%$$

Leaving

Basis: 1 lb mol at 70°F, 740 mm Hg

Actual: $p_{\text{vap}} = 18 \text{ mm Hg}$ $p_{\text{vapor-free air}} = 740 - 18 = 722 \text{ mm Hg}$ Saturated $p_{\text{vap}} = 19 \text{ mm Hg}$ $p_{\text{vapor-free air}} = 740 - 19 = 721 \text{ mm Hg}$

$$\% \text{ Humidity} = \frac{\frac{18}{722}}{\frac{19}{721}} (100)$$

$$= 94.6\%$$

(e) Basis: 1000 ft³ of mixture at 740 mm Hg and TEnteringVol % H₂O = 0.676 %Vol H₂O = (0.00676)(1000 ft³) = 6.76 ft³

@ 26.8 °C and 740 mm Hg

$$6.76 \text{ ft}^3 \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \left| \frac{492^\circ\text{R}}{540^\circ\text{R}} \right| \left| \frac{740 \text{ mm Hg}}{760 \text{ mm Hg}} \right| \left| \frac{18 \text{ lb}}{1 \text{ lb mol}} \right|$$

$$= 0.30 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3$$

at 80°F and 740 mm Hg

LeavingVol % H₂O = 2.43 %Vol H₂O = (0.0243)(1000 ft³) = 24.3 ft³

@ 21.0 °C and 740 mm HG

$$24.3 \text{ ft}^3 \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \left| \frac{740 \text{ mm Hg}}{760 \text{ mm Hg}} \right| \left| \frac{492^\circ\text{R}}{530^\circ\text{R}} \right| \left| \frac{18 \text{ lb}}{1 \text{ lb mol}} \right|$$

$$= 1.10 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3$$

at 70°F and 740 mmHg

(f)

Entering

$$\frac{0.30}{0.99324}$$

$$= 0.302 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3 \text{ vapor free air}$$

Leaving

$$\frac{1.10}{0.9757}$$

$$= 1.127 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3 \text{ vapor free air}$$

(g) Basis: 800,000 ft³/day at 80°F, 740 mm HgEntering

$$\text{Vol \% air} = 99.324 \%$$

$$\text{Vol dry air} = (800,000)(0.99324)$$

$$= 794,600 \text{ ft}^3$$

$$\text{Vol H}_2\text{O vapor} = (800,000)(0.00676)$$

$$= 5400 \text{ ft}^3 \text{ at } 80^\circ\text{F}, 740 \text{ mm Hg}$$

$$5400 \text{ ft}^3 \left(\frac{740}{760} \right) \left(\frac{492}{540} \right)$$

$$= 4790 \text{ ft}^3 \text{ at SC}$$

$$\text{Water evaporated} = 17,535 - 4,790 = 12,745 \text{ ft}^3 \text{ at SC}$$

$$\frac{12,745 \text{ ft}^3}{359 \text{ ft}^3} \left| \frac{1 \text{ lb mol}}{18 \text{ lb}} \right| = 639 \text{ lb H}_2\text{O/day}$$

Leaving

$$\text{Vol dry air} = 794,600 \left(\frac{530}{540} \right)$$

$$= 779,900 \text{ ft}^3 \text{ at } 70^\circ\text{F}$$

$$\text{Vol \%} = 97.57 \%$$

$$\text{Total vol} = \frac{779,900}{0.9757} = 799,300 \text{ ft}^3$$

$$\text{Vol H}_2\text{O vap} = 799,300 - 779,900$$

$$= 19,400 \text{ ft}^3 \text{ at } 70^\circ\text{F}, 740 \text{ mm Hg}$$

$$19,400 \left(\frac{492}{530} \right) \left(\frac{740}{760} \right) = 17,535 \text{ at SC}$$

Part g could also be worked using part f and the volume of dry air:

Entering

$$794,600 \text{ ft}^3 \text{ dry air}$$

$$0.302 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3 \text{ dry air (see f)}$$

$$\frac{794,600}{1000} \left| \frac{0.302}{1} \right| = 240 \text{ lb H}_2\text{O}$$

Leaving

$$779,900 \text{ ft}^3 \text{ dry air}$$

$$1.127 \text{ lb H}_2\text{O} / 1000 \text{ ft}^3 \text{ dry air (see f)}$$

$$\frac{779,900}{1000} \left| \frac{1.127}{1} \right| = 879 \text{ lb H}_2\text{O}$$

(continues)

Solutions - Chapter - 4

$$\text{Water evaporated} = 879 - 240 = \boxed{639 \text{ lb H}_2\text{O} / \text{day}}$$

$$4.124 \quad p_{\text{H}_2\text{O}} \text{ at } 70^\circ\text{F} = 19.0 \text{ mm Hg}$$

$$p_{\text{H}_2\text{O}}^* \text{ at } 140^\circ\text{F} = 149.4 \text{ mm Hg}$$

$$p_{\text{H}_2\text{O}} \text{ at } 70^\circ\text{F} = (19.0) (0.50) = 9.5 \text{ mm Hg}$$

$$p_{\text{H}_2\text{O}} \text{ at } 140^\circ\text{F} = (149.4) (0.80) = 119.4 \text{ mm Hg}$$

Basis: 760 mol wet air in, or use 200 lb H₂O entering

$$\text{Balances: Air: } \left(\frac{750.5}{760} \right) F = \left(\frac{640.5}{760} \right) P$$

$$\text{H}_2\text{O: } \left(\frac{9.5}{760} \right) F + \left(\frac{200}{18} \right) = \left(\frac{119.4}{760} \right) P$$

$$\text{or: } \frac{119.4 \text{ mol H}_2\text{O out}}{640.6 \text{ mol BDA out}} \left| \frac{750.5 \text{ mol BDA in}}{760 \text{ mol W.A. in}} \right| = \frac{140 \text{ mol H}_2\text{O out}}{760 \text{ mol W.A. in}}$$

$$140 - 9.5 = 130.5 \frac{\text{mol H}_2\text{O evap.}}{760 \text{ mol W.A. in}}$$

$$\frac{760 \text{ mol W.A. in}}{130.5 \text{ mol H}_2\text{O}} \left| \frac{750.5}{760.0} \right| \left| \frac{200 \text{ lb H}_2\text{O}}{\text{hr}} \right| \left| \frac{\text{lb mol}}{18 \text{ lb}} \right| \left| \frac{359 \text{ ft}^3}{\text{lb mol}} \right| \left| \frac{530}{492} \right| = \boxed{24,700 \frac{\text{ft}^3}{\text{hr}} \text{ BDA in}}$$

4.125

Basis: 1000 ft³ wet air at 30°C and 740 mm Hg

$$p_{\text{H}_2\text{O}}^* = 1.253 \text{ in Hg} \\ = 31.9 \text{ mm Hg}$$

$$p_{\text{air}} = 740 - 31.9 \\ = 708.1 \text{ mm Hg}$$

$$(a) \frac{1000}{740} \left| \frac{31.8}{760} \right| \left| \frac{740}{303} \right| \left| \frac{273}{359} \right| \left| \frac{18}{2} \right| = \boxed{0.946 \text{ lb H}_2\text{O}}$$

(continued)

$$(b) \frac{1000(740 - 31.8)}{740} = \boxed{958 \text{ ft}^3 \text{ dry air at 740 mm Hg and } 30^\circ\text{C}}$$

or 1000 ft³ at 708.1 mm Hg and 30 °C

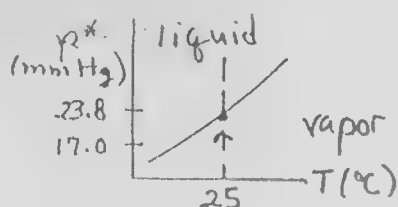
4.126

$$p^*_{25^\circ\text{C}} = 23.8 \text{ mm Hg (3.17 kPa)}$$

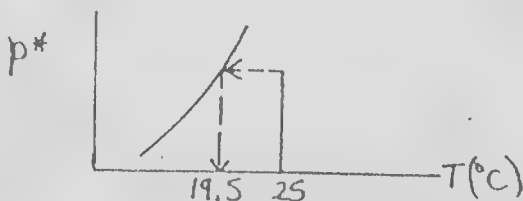
$$p^*_{19.5^\circ\text{C}} = 17.0 \text{ mm Hg (2.27 kPa)}$$

Assume a constant pressure process for (1).

- (1) At 100 kPa, $p_{\text{H}_2\text{O}}$ is constant and the saturation temperature is the temperature at which the water vapor starts to condense, namely 19.5°C.



- (2) At 25°C, compression increases p^* (volume changes), but $y_{\text{H}_2\text{O}}$ is constant.



$$p_{\text{H}_2\text{O}} = p_{\text{tot}} y_{\text{H}_2\text{O}} \text{ so that } \frac{p_{\text{tot},2}}{p_{\text{tot},1}} = \frac{p_{\text{H}_2\text{O},2}}{p_{\text{H}_2\text{O},1}} = \frac{p^*_{25^\circ\text{C}}}{p^*_{19.5^\circ\text{C}}}$$

$$p_{\text{tot},2} = 100 \text{ kPa} \left(\frac{23.8}{17.0} \right) = \boxed{140 \text{ kPa}}$$

- (3) Basis: 100 mol wet vapor

$$p^*_{(\text{H}_2\text{O})_2} = p y_{(\text{H}_2\text{O})_2}$$

$$\frac{n_{\text{H}_2\text{O}}}{n_{\text{tot}}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{tot}}}$$

		mol fr.
Air	97.73	0.99795
H ₂ O	0.908	0.009205
	98.683	1.0000

(continued)

Initial
mol or kPa

Air: $100 - 2.27 = 97.73$

H₂O: $2.27 = \frac{2.27}{100.00}$

To remove 60% of water vapor,

$$n_2 = 0.4 (2.27) = 0.908 \text{ mol}$$

$$p^*_{H_2O} = 100 \left(\frac{0.908}{97.73 + 0.908} \right) = 0.9205 \text{ kPa}$$

(6.906 mm Hg)

6.91 mm Hg corresponds to 6.22°C.

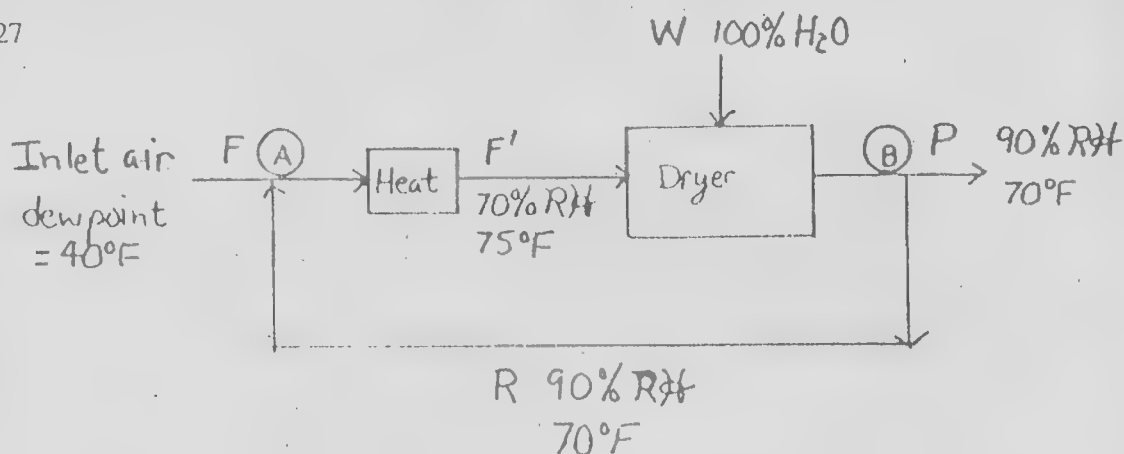
(4) At constant temperature, the pressure increases until.

$$y_{(\text{H}_2\text{O})_2} = 0.9205/100 = 0.009205, \text{ (saturation at } 25^\circ\text{C and } p_i)$$

$$p^*_{25^\circ\text{C}} = p_{\text{t}_2} y_{(\text{H}_2\text{O})_2} \quad p_{\text{t}_2} = \frac{3.17 \text{ kPa}}{0.009205} = \boxed{344 \text{ kPa}}$$

Process (1) is probably more economical because the 344 kPa requires higher cost equipment.

4.127



Data:

T (°F)	p* (in Hg)	p* (psia)	PH ₂ O (in Hg)	$\frac{p_T - p_{H_2O}}{p_{tot}}$	
				y _{H₂O}	y _{air}
40	0.2478	0.1217	0.2478	0.00828	0.992
70	0.7387	0.3628	(0.9)(0.7387)=0.6648	0.0222	0.9778
75	0.8748	0.4297	(0.7)(0.8748)=0.6124	0.0205	0.9795

(continued)

Basis: $F = 100 \text{ mol (wet)}$ Overall balancesUnknowns = P, W Balances: air, H_2O

Air balance:

$$100 (0.992) = P (0.9778)$$

$$P = 101.45 \text{ lb mol}$$

Balances at $\textcircled{A}$ Unknowns: F', R Balances: air, H_2O Total balance at $\textcircled{A}$ (plus heater)

$$F' = F + R = 100 + R$$

Air balance at $\textcircled{A}$ (plus heater)

$$100 (0.992) + R (0.9778) = (100 + R) (0.9795)$$

$$R = 735.3$$

(B) Total wet air leaving dryer

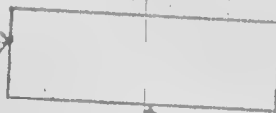
$$735.3 + 101.45 = 836.75$$

$$\frac{R}{R+P} = \frac{735.3}{836.75} = \boxed{0.88}$$

4.128

$$\begin{array}{c} C \ x \\ H \ \frac{1-x}{1.00} \end{array}$$

F

Air
(Dry)

$$\begin{array}{c} O_2 \ 0.21 \\ N_2 \ 0.79 \\ \hline 1.00 \end{array}$$

P

Orsat

$$CO_2 \ 0.10$$

$$O_2 \ y_{O_2}$$

$$N_2 \ \frac{0.9 - y_{O_2}}{1.00}$$

Dew point
= $47^\circ C$

$$p^* = 10.54 \text{ kPa}$$

 $p_{\text{dry gas}}$

$$= 116 - 10.54$$

= 105.46 (continued)

Basis: 1 mol P

Unknowns: x, F, A, y_{O_2}, W Balances: C, H, O, N plus dew point for H_2O is given so mol fraction H_2O is known

All balances are in moles.

$$C: \quad Fx = P(0.10) \quad \frac{W}{P} = \frac{10.54}{105.46}$$

$$H: \quad F(1-x) = W(2)$$

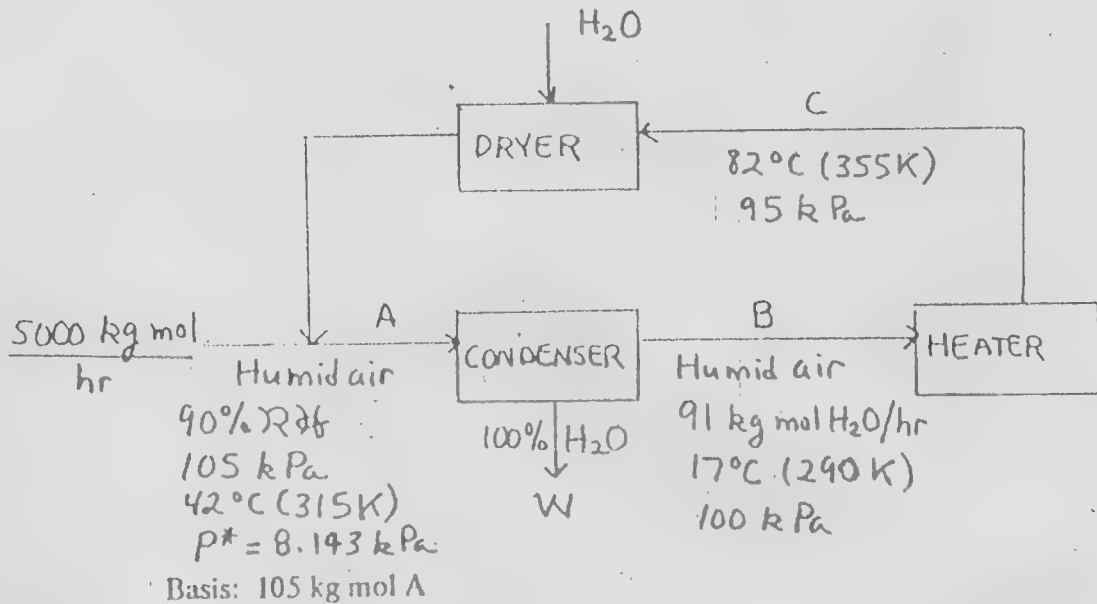
$$N_2: \quad A(0.79) = P(0.9 - y_{O_2})$$

$$O_2: \quad A(0.21) = P(0.10 + y_{O_2}) + \frac{W}{2}$$

$$x = 0.33$$

$$\frac{1-x}{x} = \frac{H}{C} = \frac{0.667}{0.333} = \boxed{2.00}$$

4.129



(continued)

Basis: 5000 kg mol air

$$RH = \frac{P_{H_2O}(100)}{P_{H_2O}}$$

$$90 = \frac{P_{H_2O}(100)}{8.143}$$

$$P_{H_2O} = 7.329 \text{ kPa}$$

$$y_{H_2O} = \frac{P_{H_2O}}{P_{total}}$$

$$y_{H_2O} = \frac{7.329}{105} = 0.0698$$

(a) The mol H_2O entering = $(5000)(0.0698) = 349 \text{ kg mol } H_2O / \text{hr}$

 H_2O balance on condenser:

(b) $W = 349 + 91 = 258 \text{ kg mol } H_2O / \text{hr}$

$$W = \frac{258 \text{ kg mol } H_2O}{18 \text{ kg mol } H_2O} = 14.33 \text{ kg mol } H_2O / \text{hr} \quad \boxed{4644 \text{ kg } H_2O / \text{hr condenses}}$$

dry air enters the condenser

$$= 5000 - 349 = 4651 \text{ kg mol}$$

Stream B: $\begin{pmatrix} H_2O & 91 \text{ kg mol} \\ \text{dry air} & 4651 \text{ kg mol} \end{pmatrix}$

$$4742 \text{ kg mol}$$

$$\frac{\text{Pressure}}{1.919} = \%$$

$$\boxed{100 \text{ kPa}}$$

(c) and (d) in B: $P_{H_2O} = 1.919 \text{ kPa}$ corresponding to $\boxed{17^\circ\text{C}}$

4.130

Basis: 100 m^3 air

(a) $P^*_{H_2O}$ at $21^\circ\text{C} = 0.3628 \text{ psia} = P_{H_2O}$

$$P_{H_2O}/P_t = V_{H_2O}/V_t = 0.01$$

$$P_t = 0.3628/0.01 = 36.28 \text{ psia}$$

(b) $S = (p)^{1.4} + (350 - T)^{1.9}$

Also p and T are related by the vapor pressure curve for water since the gas has to be saturated for condensation to take place. From Lange's Handbook,

(continued)

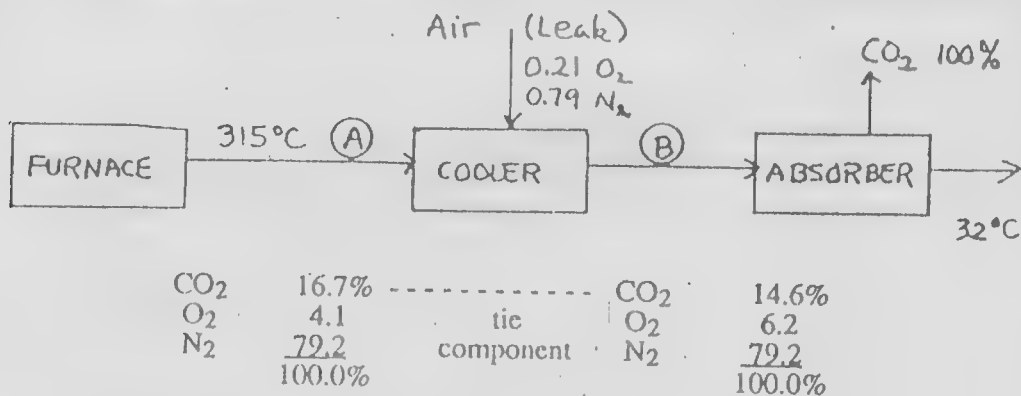
$$\log_{10} p^* = 8.10765 - \left(\frac{1750.286}{235.0 + T} \right) \text{ for } T < 60^\circ\text{C}$$

For minimum cost:

$$\frac{d\$}{dT} = 0 = \left[\frac{d \left[(p)^{1.4} + (350 - T)^{1.9} \right]}{dT} \right]_p + \left[\frac{d \left[(p)^{1.4} + (350 - T)^{1.9} \right]}{dp} \right]_T \frac{dp}{dT}$$

where $dp/dT = (2.3)(175.28)(p)/(T - 38)^2$. Solving the equations simultaneously, economical values are **5.8 psia, 76°C.**

4.131



Basis: 100 kg mol gas to absorber

O₂ Balance:

$$\frac{100 \text{ kg mol at (B)}}{14.6 \text{ kg mol CO}_2} \left| \frac{16.7 \text{ kg mol CO}_2}{100 \text{ kg mol at (A)}} \right. = 1.144 \text{ mol gas (B)/mol gas at (A)}$$

$$1.144 - 1.00 = 0.144 \text{ mol air leaking in/mol gas at (A)}$$

$$\frac{0.144 \text{ kg mol air}}{1.00 \text{ kg mol (A)}} \left| \frac{1.00 \text{ kg mol gas at (A)}}{1.144 \text{ kg mol at (B)}} \right. = 0.126 \text{ mol dry air/mol (B)}$$

$$= 0.126 \frac{\text{m}^3 \text{ air at } T \text{ and } p}{\text{m}^3 \text{ dry gas at (B) at } T \text{ and } p}$$

(continued)

Solutions - Chapter - 4

For wet gas, add H_2O . Assume saturated:

$$\text{At } 32^\circ\text{C } p^*_{H_2O} = 4.718 \text{ kPa}$$

$$P_{\text{gas}} = P_t - p^*_{H_2O} = 101.3 - 4.718 = 96.58 \text{ kPa}$$

$$\frac{n_{\text{wet gas}}}{n_{\text{dry gas}}} = \frac{P_t}{P_{\text{gas}}} \quad 0.126 \left(\frac{101.3}{96.58} \right) = \boxed{0.132 \text{ m}^3}$$

4.132

$$\text{Basis: 1 hr} \quad 400 (0.50) = 200 \text{ lb dry sludge}$$

$$\frac{200 \text{ lb dry sludge}}{90 \text{ lb dry sludge}} \left| \frac{10 \text{ lb } H_2O}{90 \text{ lb dry sludge}} \right| = 22.2 \text{ lb } H_2O \text{ leaving}$$

Sludge Balance:

in out

$$\text{Weight of } H_2O \text{ removed} = 200 - 22.2 = 177.8$$

$$\text{Less centrifuge removal} = \underline{100.0}$$

$$\text{Wet water remaining (goes into air)} = 77.8 \text{ lb/hr}$$

$$\left. \begin{array}{l} 70^\circ\text{F} \\ 50\% \text{RH} \\ 760 \text{ mmHg} \end{array} \right\}$$

$$p^* = 0.363 \text{ psi} = 18.6 \text{ mmHg}$$

$$P_{H_2O} = (0.5)18.6 = 0.0124 \text{ mol } H_2O \quad [\text{BDA} = \text{bone dry air}]$$

$$\text{pair } 750.7 \text{ mol BDA}$$

$$\left. \begin{array}{l} 100^\circ\text{F} \\ 94^\circ\text{F dew pt} \\ 750 \text{ mmHg} \end{array} \right\}$$

$$p^* = 0.790 \text{ psia} = 40.8 \text{ mmHg}$$

$$P_{H_2O} = 40.8 = 0.0577 \text{ mol } H_2O$$

$$\text{pair } 709 \text{ mol BDA}$$

$$0.0575 - 0.0124 = 0.0451 \text{ mol } H_2O \text{ gained/mol BDA}$$

$$\frac{1 \text{ mol BDA}}{0.0451 \text{ mol } H_2O} \left| \frac{77.8 \text{ lb } H_2O}{1 \text{ hr}} \right| \left| \frac{1 \text{ lb mol } H_2O}{18 \text{ lb } H_2O} \right| = 95.7 \frac{\text{lb mol BDA}}{\text{hr}}$$

$$\text{Volume of moist air req'd is: } 95.7 (1.024) \left(\frac{530}{492} \right) (359) = \boxed{37,920 \text{ ft}^3 \text{ at } 70^\circ\text{F, } 760 \text{ mmHg}}$$

4.133 Basis: 1 mol pure benzene feed to reactor

$$(a) \text{ feed } N_2: \frac{18 \text{ mol } O_2}{21 \text{ mol } O_2} \left| \frac{79 \text{ mol } N_2}{21 \text{ mol } O_2} \right. = 67.7 \text{ mol } N_2$$

$$\text{total output mol: } \frac{67.7 \text{ mol } N_2}{0.80 \text{ mol } N_2} \left| \frac{1 \text{ mol out}}{0.80 \text{ mol } N_2} \right. = 84.5 \text{ mol (dry)}$$

$$\text{output MaAc: } (84.5 \text{ mol}) (0.0076) = 0.641 \text{ mol}$$

$$\text{From stoichiometric equation: moles benzene reacted} = 0.641 \text{ mol}$$

H₂O entering with benzene: benzene is accompanied by H₂O vapor, but benzene and H₂O are at their vapor pressure.

T		P _{total} , psia
180°F		23.191
190°F		27.847
$\frac{n_{H_2O}}{n_{benzene}}$	$= \frac{7.51}{15.68} =$	$\frac{P_{H_2O}}{P_{benzene}}$

$$\frac{1 \text{ mol benzene in}}{15.68 \text{ moles benzene}} \left| \frac{7.51 \text{ moles } H_2O}{15.68 \text{ moles benzene}} \right. = 0.48 \text{ mol } H_2O$$

H₂O entering with air:

$$\frac{P_{H_2O}}{P^*_{H_2O}} = 0.5 \quad p^*_{H_2O} \text{ at } 150^\circ\text{F} = 3.718 \text{ psia}$$

$$P_{H_2O} = (0.5) (3.718) = 1.86 \text{ psia}$$

$$P_{air} = 14.7 - 1.86 = 12.84 \text{ psia}$$

$$\frac{n_{H_2O}}{n_{air}} = \frac{P_{H_2O}}{P_{air}} = \frac{1.86}{12.84} \text{ mol } H_2O = \frac{84.7 \text{ mol air}}{12.84 \text{ mol air}} \left| \frac{1.86 \text{ mol } H_2O}{12.84 \text{ mol air}} \right. = 12.25 \text{ mol}$$

$$\text{Total mol } H_2O \text{ entering reactor} = 0.48 + 12.25 = 23.73 \text{ mol } H_2O$$

(continued)

Balances about Reactor

In				Out					
H ₂ O	Bz	O ₂	N ₂	H ₂ O	N ₂	O ₂	CO ₂	Bz	MaAc

O₂ Balance:

$$\frac{12.73}{2} + 1(0) + 18 + 0 = \frac{x}{2} + 0 + y + z + 0 + 2(0.641)$$

H₂ balance:

$$12.73 + 3(1) + 0 + 0 = x + 0 + 0 + 0 + 3w + 2(0.641)$$

C balance:

$$0 + 6(1) + 0 + 0 = 0 + 0 + 0 + z + 6w + 4(0.641)$$

Total mol balance is not possible but we know from extra information given (N₂ = 80% mol = 84.5. Consequently, on dry basis

$$84.5 = 67.7 + y + z + w = 0.641$$

Solving simultaneously:

$$x = 14.0 \quad y = 13.51 \quad z = 2.54 \quad w = 0.15$$

$$\text{Moles benzene undergoing reaction} = 1.0 - 0.15 - 0.641 = \boxed{0.21 \text{ mol}}$$

Part (a) alternateLet $y = 1b$ moles benzene reacting by (2)

$$85 = C_6H_6(1 - 0.641 - y) + O_2(18 + 2.9 - 7.5y) + CO_2(1.29 + 6y) + 0.641 + 68$$

$$85 = 1.0 - 0.641 - y + 18 - 2.9 - 7.5y + 1.29 + 6y + 0.641 + 68$$

$$\text{Solving: } \boxed{y = 0.196 \text{ mol benzene / mol benzene fed}}$$

Balances around Dehydrator

$$\text{mol H}_2\text{O with C}_4\text{H}_4\text{O}_4: \frac{0.641}{12} \times 88 = 4.70 \text{ mol}$$

$$\text{mol H}_2\text{O by reaction: } 0.641(1) = \underline{0.641 \text{ mol}}$$

$$\text{Total} \quad 5.34 \text{ mol}$$

(con

$$\frac{\text{lb H}_2\text{O}}{\text{lb mol benzene}} = \frac{5.34 \text{ mol}}{1 \text{ lb mol}} \left| \frac{18 \text{ lb H}_2\text{O}}{\text{lb mol H}_2\text{O}} \right| = 96.5 \text{ lb H}_2\text{O}$$

(c) Exit gases from scrubber are

Comp.	mol	mol %
N ₂	67.70	64.0
O ₂	13.51	12.8
CO ₂	2.54	2.4
C ₆ H ₆	0.15	0.8
H ₂ O	21.10	20.0
Total	106.00	100.0

Gas is saturated at 142°F

$$P_{\text{H}_2\text{O}}^* = 3.04 \text{ psia}$$

$$P_{\text{gas}} = 14.7 - 3.04 = 11.66 \text{ psia}$$

$$\left(\frac{P_{\text{H}_2\text{O}}^*}{P_{\text{gas}}} \right)$$

(d) Water Balance about Scrubber:

$$\text{mol H}_2\text{O added} = 21.10 + 4.70 - 13.70 = 12.10 \text{ mol}$$

$$\frac{\text{lb H}_2\text{O added}}{\text{lb mol benzene fed}} = \frac{12.10 \text{ mol}}{1 \text{ lb mol}} \left| \frac{18 \text{ lb H}_2\text{O}}{\text{lb mol H}_2\text{O}} \right| = 217.5 \text{ lb H}_2\text{O}$$

10 gms	10%	5%	113.4276	1 km	11%
8.312	10 gms	1%	10.558	3.9208 ft	1 km
					19%

5.1

Basis: 1 lb_m

252 cal

$$a. \frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \frac{252 \text{ cal}}{1 \text{ Btu}} \right| \frac{1 \text{ lb}_m}{0.454 \text{ kg}} = \boxed{2.5 \times 10^4 \text{ cal/kg}}$$

$$b. \frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \frac{1.055 \times 10^3 \text{ J}}{1 \text{ Btu}} \right| \frac{1 \text{ lb}_m}{0.454 \text{ kg}} = \boxed{1.048 \times 10^5 \text{ J/kg}}$$

$$c. \frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \frac{2.930 \times 10^{-4} (\text{kW})(\text{hr})}{1 \text{ Btu}} \right| \frac{1 \text{ lb}_m}{0.454 \text{ kg}} = \boxed{2.91 \times 10^{-2} \frac{(\text{kW})(\text{hr})}{\text{kg}}}$$

$$d. \frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \frac{7.7816 \times 10^2 (\text{ft})(\text{lb}_f)}{1 \text{ Btu}} \right| = \boxed{3.5 \times 10^4 (\text{ft})(\text{lb}_f) / \text{lb}_m}$$

1 Btu = 7.7816 x 10^2

5.2

1 Btu = 2.930

$$a. \frac{4.184 \text{ J}}{(\text{g})(^\circ\text{C})} \left| \frac{9.484 \times 10^{-4} \text{ Btu}}{1 \text{ J}} \right| \frac{1 \text{ g}}{2.2 \times 10^{-3} \text{ lb}_m} \left| \frac{1^\circ\text{C}}{1.8^\circ\text{F}} \right| = \boxed{\frac{1.00}{(\text{lb}_m)(^\circ\text{F})}}$$

$$b. \frac{-41.6 \text{ J}}{\text{kg}} \left| \frac{9.484 \times 10^{-4} \text{ Btu}}{1 \text{ J}} \right| \frac{\text{kg}}{1000 \text{ g}} \left| \frac{1 \text{ g}}{2.20 \times 10^{-3} \text{ lb}_m} \right| = \boxed{-0.0179 \frac{\text{Btu}}{\text{lb}_m}}$$

$$c. \frac{0.59 (\text{kg})(\text{m})}{(\text{s}^3)(\text{K})} \left| \frac{1 \text{ N}}{(\text{kg})(\text{m})(\text{s}^{-2})} \right| \left| \frac{(\text{J})(\text{m}^{-1})}{1 \text{ N}} \right| \left| \frac{9.484 \times 10^{-4} \text{ Btu}}{1 \text{ J}} \right| \left| \frac{1 \text{ m}}{3.2808 \text{ ft}} \right| \left| \frac{3600 \text{ s}}{\text{hr}} \right| \left| \frac{1 \text{ K}}{1.8^\circ\text{F}} \right|$$

$$= \boxed{0.341 \frac{\text{Btu}}{(\text{ft})(\text{hr})(^\circ\text{F})}}$$

1 Btu = 2.93 x 10^3

5.3

$$a. \frac{6000 \text{ Btu}}{(\text{hr})(\text{ft}^2)} \left| \frac{252 \text{ cal}}{1 \text{ Btu}} \right| \left| \frac{\text{hr}}{3600 \text{ s}} \right| \left| \frac{\text{ft}^2}{30.48^2 \text{ cm}^2} \right| = \boxed{0.4521 \frac{\text{cal}}{(\text{s})(\text{cm}^2)}}$$

$$b. \frac{2.3 \text{ Btu}}{(\text{lb})(^\circ\text{F})} \left| \frac{252 \text{ cal}}{1 \text{ Btu}} \right| \left| \frac{\text{lb}}{453.6 \text{ g}} \right| \left| \frac{(\Delta) 1.8^\circ\text{F}}{(\Delta) ^\circ\text{C}} \right| = \boxed{2.3 \frac{\text{cal}}{(\text{g})(^\circ\text{C})}}$$

$$c. \frac{200 \text{ Btu}}{(\text{hr})(\text{ft})(^\circ\text{F})} \left| \frac{1,055 \text{ J}}{1 \text{ Btu}} \right| \left| \frac{\text{hr}}{3600} \right| \left| \frac{\text{ft}}{30.45 \text{ cm}} \right| \left| \frac{(\Delta) 1.8^\circ\text{F}}{(\Delta) ^\circ\text{C}} \right| = \boxed{3.46 \frac{\text{J}}{(\text{s})(\text{cm})(^\circ\text{C})}}$$

(continued)

$$d. \frac{10.73 \text{ (lb}_p\text{)} (\text{ft}^3)}{(\text{in.}^2) (\text{lb mol}) (^{\circ}\text{R})} \left| \frac{144 \text{ in.}^2}{\text{ft}^2} \right| \left| \frac{\text{Btu}}{778 \text{ (ft)} (\text{lb}_p)} \right| \left| \frac{\text{lb mol}}{453.6 \text{ g mol}} \right| \left| \frac{1.055 \times 10^3 \text{ J}}{\text{Btu}} \right| \left| \frac{(\Delta) 1.8^{\circ}\text{R}}{(\Delta)^{\circ}\text{K}} \right|$$

$$= \boxed{8.31 \frac{\text{J}}{(\text{g mol})(^{\circ}\text{K})}}$$

5.4 To convert to $\text{J}/(\text{min})(\text{cm}^2)(^{\circ}\text{C})$, we set up the dimensional equation as follows

$$h = \frac{0.026 \text{ G}^{0.6} \text{ Btu}}{D^{0.4} (\text{hr}) (\text{ft}^2) (^{\circ}\text{F})} \left| \frac{1055 \text{ J}}{1 \text{ Btu}} \right| \left| \frac{1 \text{ hr}}{60 \text{ min}} \right| \left| \left(\frac{1 \text{ ft}}{12 \text{ in.}} \right)^2 \right| \left| \left(\frac{1 \text{ in.}}{2.54 \text{ cm}} \right)^2 \right| \left| \frac{1.8^{\circ}\text{F}}{1^{\circ}\text{C}} \right|$$

$$= 8.86 \times 10^{-4} \frac{\text{G}^{0.6} \text{ J}}{D^{0.4} (\text{min})(\text{cm}^2)(^{\circ}\text{C})}$$

If G and $\hat{I}$ are to be used in units of

$$G': \frac{\text{g}}{(\text{min})(\text{cm}^2)}$$

$$D': \text{cm}$$

An additional conversion is required:

$$h' = \frac{8.86 \times 10^{-4} \left[\frac{G' (\text{g})}{(\text{min})(\text{cm}^2)} \left| \frac{1 \text{ lb}_m}{454 \text{ g}} \right| \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \left| \left(\frac{2.54 \text{ cm}}{1 \text{ in.}} \right)^2 \right| \left| \left(\frac{12 \text{ in.}}{1 \text{ ft}} \right)^2 \right| \right]^{0.6} 1 \text{ cal}}{\left[\frac{D' (\text{cm})}{2.54 \text{ cm}} \left| \frac{1 \text{ in.}}{12 \text{ in.}} \right| \right]^{0.4} (\text{min})(\text{cm}^2)(^{\circ}\text{C})}$$

$$= 6.23 \times 10^{-2} \frac{(G')^{0.6} \text{ J}}{(D')^{0.4} (\text{min})(\text{cm}^2)(^{\circ}\text{C})}$$

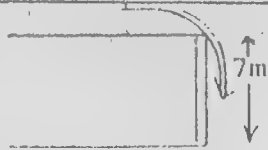
5.5 a. $\frac{1 \text{ lb fat}}{2.2 \text{ lb}} \left| \frac{1 \text{ kg}}{\text{kg}} \right| \left| \frac{7,700 \text{ k cal}}{\text{kg}} \right| \left| \frac{\text{day}}{500 \text{ k cal}} \right| = \boxed{7 \text{ days}}$

b. $\frac{1 \text{ lb fat}}{2.2 \text{ lb}} \left| \frac{1 \text{ kg}}{\text{kg}} \right| \left| \frac{7,700 \text{ k cal}}{\text{kg}} \right| \left| \frac{4,184 \text{ k J}}{1 \text{ k cal}} \right| \left| \frac{\text{km}}{400 \text{ k J}} \right| \left| \frac{0.6214 \text{ mi}}{1 \text{ km}} \right| = \boxed{22.75 \text{ mi}}$

c. Total energy consumed is the same. The higher power consumption is compensated for in the shorter travel time.

5.21 ΔH and ΔU are zero because ΔH and ΔU are point (state) functions.

5.22 Filled reservoir



Assume 7 meters is a constant level difference hence $h = 7\text{m}$

For one-half of the cycle:

$$m = \rho Ah = \frac{10^3 \text{ kg}}{\text{m}^3} \left| \frac{23 \text{ km}^2}{\text{m}^2} \right| \left| \frac{7 \text{ m}}{\text{m}} \right| \left| \left(\frac{10^3 \text{ m}}{1 \text{ km}} \right)^2 \right| = 1.61 \times 10^{11} \text{ kg}$$

$$\text{PE} = \frac{1.61 \times 10^{11} \text{ kg}}{\text{kg}} \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{7 \text{ m}}{\text{m}} \right| \left| \frac{1 \text{ J}}{(1 \text{ kg})(\text{m}^2/\text{s}^2)} \right| = 1.10 \times 10^{13} \text{ J}$$

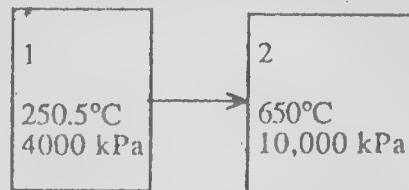
For a complete cycle:

$$\frac{1.10 \times 10^{13} \text{ J}}{\text{cycle}} \left| \frac{2 \text{ cycles}}{\text{cycle}} \right| \left| \frac{0.85}{370 \text{ min}} \right| \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = 5.06 \times 10^8 \text{ J/s}$$

$$\boxed{\text{or } 5.06 \times 10^8 \text{ W}}$$

5.23

Basis: 1 kg steam



$\Delta U = \Delta H - \Delta pV$ or use U values directly from SI tables or computer code.

Data here taken from the steam tables.

	State 1 (assumed saturated)	State 2 (superheated)
T	250.5°C (523.5 K)	650°C (923 K)
	482°F	1202°F
	4000 kPa abs.	10,000 kPa abs.
p	580 psia	1450 psia
$\hat{V}$	0.498 m ³ /kg	0.04117 m ³ /kg
ΔU	2602 kJ/kg	3338 kJ/kg
ΔH (ref. satd liquid at 0°C)	2801 kJ/kg	3742 kJ/kg

(continued)

Basis: 1 kg steam

a. From $\Delta U_2 - \Delta U_1$: $3338 - 2602 = \boxed{736 \text{ kJ/kg steam}}$

b. From ΔH data:

$$\Delta U = \Delta H - \Delta pV = (3742 - 2801) - [10,000 (0.04117) - 4000 (0.0498)]$$

$$= \boxed{720 \text{ kJ/kg (311 Btu/lb)}}$$

5.24

Basis: 10 lb mol ideal gas

(a) Use $pV = nRT$ or

$$(1) \frac{10 \text{ lb mol}}{\text{lb mol}} \left| \frac{359 (\text{ft})^3}{1 \text{ atm}} \right| \frac{1 \text{ atm}}{100 \text{ atm}} \frac{500^\circ\text{R}}{492^\circ\text{R}} = \boxed{36.5 (\text{ft})^3 @ 100 \text{ atm, } 40^\circ\text{F}}$$

$$(2) \frac{100 \text{ atm}}{500^\circ\text{R}} \frac{900^\circ\text{R}}{500^\circ\text{R}} = \boxed{180 \text{ atm}}$$

$$(3) \Delta H = (\Delta \hat{H}_2 - \Delta \hat{H}_1) 10 = 10 [300 + 8.0 (440) - (300 + 8.0 (4.0))] = \boxed{32,000 \text{ Btu}}$$

(b) The equation for ΔH is based on specified reference conditions.

$\Delta \hat{H} = 0$ when $300 = -8T$ or $T_{\text{ref}} = -37.5^\circ\text{F} = -38.5^\circ\text{C}$. Let U have the same reference temperature.

$$\Delta \hat{U} = \Delta \hat{H} - \Delta p \hat{V} = \Delta \hat{H} - \Delta RT$$

$$\frac{300 \text{ Btu}}{\text{lb mol}} \left| \frac{1 \text{ lb mol}}{454 \text{ g mol}} \right| \frac{252 \text{ cal}}{\text{Btu}} = \frac{167 \text{ cal}}{\text{g mol}} \quad T_{\text{F}} = 1.8T_{\text{C}} + 32$$

$$\frac{8.0 \text{ Btu}}{(\text{lb mol}) (^\circ\text{F})} \left| \frac{252 \text{ cal}}{\text{Btu}} \right| \frac{\text{lb mol}}{454 \text{ g mol}} (1.8T_{\text{C}} + 32)$$

$$= \frac{8.0 T_{\text{C}} \text{ cal}}{(\text{g mol}) (^\circ\text{F})} + 142 \text{ cal/g mol}$$

(continued)

$$\begin{aligned}\Delta U &= 167 + 142 + 8.0 T^{\circ}\text{C} - R (T_{\text{ABS}} - T_{\text{ABS.REF}}) \\ &= 309 + 8.0 T^{\circ}\text{C} - 1.987 (T^{\circ}\text{C} + 38.5)\end{aligned}$$

$$\Delta U = 232 + 6.01 T^{\circ}\text{C}$$

5.25

Use the same reference state, so that

$$\Delta \hat{H} = \Delta \hat{U} + \Delta (p\hat{V})$$

For one mole of an ideal gas: $p\hat{V} = RT$

$$\Delta \hat{U} = \Delta \hat{H} - \Delta RT$$

$$\begin{aligned}&= 6.05 \times 10^5 \frac{\text{J}}{\text{kg mol}} - \frac{8.314 \text{ J}}{(\text{g mol})(\text{K})} \left| \frac{10^3 \text{ g mol}}{1 \text{ kg mol}} \right| \frac{100 \text{ K}}{1} \\ &= 6.05 \times 10^5 - 8.314 \times 10^5 \\ &= \boxed{2.26 \times 10^5 \text{ J/kg mol}}\end{aligned}$$

5.26

(a)	T	(f)	F
(b)	F	(g)	F
(c)	F	(h)	F
(d)	T	(i)	T
(e)	F	(j)	T

Solutions-Chapter-5

5.27

To illustrate the approach developed, Case 2, the first level of control, will be compared to the base case, Case 1 (refer to Table 1).

The level of emission reduction for case 2 is 250 lbs/day or 91,250 lbs/year. This is achieved by an added investment of \$110,000 and an increase in annual operating cost of \$7,500. Also, an additional 166 MWH of power would be required to run the emission control equipment. This requires the electric utility to use an additional 17.098×10^8 BTU's/yr. This, in turn, will generate additional pollutants, with the amount depending on the type of fuel used. If natural gas is used, since it generates 0.2246 lbs of emissions per million BTU, then the added emission level is:

$$166 \times 10^3 \times \frac{17.098 \times 10^8 \text{ BTU}}{\text{yr}} \times \frac{0.2246 \text{ lbs}}{10^6 \text{ BTU}} = 384 \text{ lbs/yr.}$$

Recip. Compressor Operation

$$28 \text{ H.P.} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{37.12 \text{ lbs}}{\text{HP} \cdot \text{hr}} = 9,105 \text{ lbs/yr.}$$

The total emissions per year then are:

Processing Plant	91,250
Power Generation	384
Compressor Operation	9,105
Total Emissions	100,739 lbs/yr

The net reduction in emissions then is:

$$\text{Net Reduction} = \text{Emissions (Case 1)} - \text{Emissions (Case 2)}$$

$$\text{Net Reduction} = 182,500 - 100,739 = 81,761 \text{ lbs/yr.}$$

To factor in the cost to achieve this reduction, we annualized the cost of the initial investment and the annual cost of operations.

$$\begin{aligned} \text{Equivalent Annual Cost} &= \$7,500 + 110,000 (\text{CRF}) \\ &= \$7,500 + 110,000 (0.15786) = \$24,865 \end{aligned}$$

where CRF = Capital recovery factor at 10% for 10 years.

Finally, the incremental cost per lb of reduction in emissions is:

$$\text{Cost/lb} = \$24,865 / 81,761 = \$0.304/\text{lb.}$$

In a similar manner, the cost per lb reduction for the other types of fuels and for the other alternatives was calculated and is summarized in Table 2.

ITEM	TABLE 2					
	CASE					
	1	2	3	4	5	6
1. C_2 emissions, lbs/yr	182,500	91,250	36,500	18,250	9,125	4,562.5
2. Total emissions reduction, lbs/yr						
a. Natural Gas		81,761	130,749	130,631	103,095	28,537
b. Fuel Oil		79,660	127,379	122,843	86,888	-5,976
c. Coal		64,637	103,206	66,982	-29,361	-253,496
3. Equivalent annual cost		\$24,865	\$38,205	\$90,512	189,603	378,576
4. Incremental cost		\$24,865	\$13,340	\$52,307	99,091	188,973
5. Cost/lb total reduction						
a. Natural Gas		0.304	0.292	0.693	1.839	6.622
b. Fuel Oil		0.312	0.300	0.737	2.182	
c. Coal		0.385	0.370	1.351		

Investment beyond Case 3 is probably unwarranted.

5.28

Btu/hr

Btu/hr

In: 140×10^6
 1275×10^6
 1415×10^6

Out: 111×10^6
 14×10^6
 5×10^6
 170×10^6
 240×10^6
 540×10^6

$$\text{Loss} = 875 \times 10^6 \text{ Btu/hr}$$

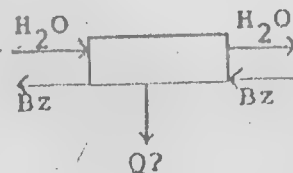
$$\% \text{ Loss} = 61.8\%$$

5.29

The general energy balance is

$$\Delta E = Q + W - \Delta [(\hat{H} + \hat{K} + \hat{P}) m]$$

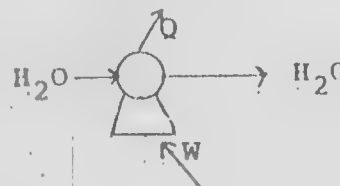
(1) (2) (3) (4) (5) (6)

(a) (1) $\Delta E = 0$ steady state flow process(2) Q may or may not be zero.

It is 0 if exchanger is insulated.

(3) $W = 0$ no mechanical work in the process(4) $\Delta H \neq 0$ (5) $\Delta K = 0$ negligible KE change(6) $\Delta P = 0$ level exchanger assumed.

$$Q = \Delta H$$

(b) (1) $\Delta E = 0$ steady state process(2) Q not zero as isothermal(3) W retain

(continue)

Solutions-Chapter-5

(4) $\Delta H \neq 0$ as pressure changes even if T is constant

(5) $\Delta K = 0$ pipe diameter same

(6) $\Delta P = 0$ level pump lines $Q + W = \Delta H$

(c) (1) $\Delta E \neq 0$ as T changes

Batch process

(2) $Q = 0$ adiabatic

(3) $W = 0$ no mechanical work

(4) $\Delta H = 0$

(5) $\Delta K = 0$

(6) $\Delta P = 0$

} no mass flow in or out

5.30 Differentiate the enthalpy equation

$$\frac{d(\Delta H_T)}{dT} = C_p(T) = 92.38 + 3.754 \times 10^{-2} T - \frac{2.186 \times 10^6}{T^2}$$

5.31 Solution via Polymath:

$$C_p = 34.5864 + 0.0356677T - 7.9955 \times 10^{-6}T^2$$

$$C_p = 34.8264 + 0.0326495T - 1.45 \times 10^{-6}T^2 - 3.6363 \times 10^{-9}T^3$$

5.32 The answer to this problem depends to some extent on the computer program used and the weights assigned each data point. A second order fit is only good above 300°C. As a guide for an answer:

$$C_p = 8.3810 + 7.9891 \times 10^{-3} T - 1.5055 \times 10^{-6} T^2$$

and

$$C_p = 8.4017 + 7.0601 \times 10^{-3} T + 1.0567 \times 10^{-6} T^2 - 1.5981 \times 10^{-9} T^3$$

with average deviations of 0.55% and 0.36% and maximum deviations of 1.48% and 0.91%.

5.33

Equation is

$$C_p = 36.7 + 0.0403T - 0.0000221 T^2$$

It is not valid to calculate confidence limits in the absence of replicate data used to evaluate the experimental error vs. the error of fit to the equation unless the equation is known to fit the data correctly, i.e., the model is a valid one.

5.34

To convert J/(g mol) (°C) to Btu/(lb mol) (°F)

$$\frac{\text{J}}{(\text{g mol}) (^\circ\text{C})} \left| \frac{1 \text{ cal}}{4.184 \text{ J}} \right| \left| \frac{1 \text{ Btu}}{252 \text{ cal}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \left| \frac{(1 \Delta ^\circ\text{C})}{(1.8 \Delta ^\circ\text{F})} \right|$$

Hence the righthand side of the heat capacity equation has to be multiplied by 1/4.184.

To convert the temperatures in °C to T in °F, substitute

$$T_{^\circ\text{C}} = \frac{T_{^\circ\text{F}} - 32}{1.8}$$

$$C_p \left(\frac{\text{Btu}}{(\text{lb mol})(^\circ\text{F})} \right) = 17.20 + 4.80 \times 10^{-2} \left(\frac{T_{^\circ\text{F}} - 32}{1.8} \right) - 3.054 \times 10^{-5} \left(\frac{T_{^\circ\text{F}} - 32}{1.8} \right)^2 + 8.308 \times 10^{-9} \left(\frac{T_{^\circ\text{F}} - 32}{1.8} \right)^3$$

5.35

a. $T_K = T_{^\circ\text{C}} + 273.2$ so that

$$C_p = 6.39 + 1.76 \times 10^{-3} (T_{^\circ\text{C}} + 273.2) - 0.26 \times 10^{-6} (T_{^\circ\text{C}} + 273.2)^2$$

Multiply the whole equation by 1/29 to get Btu/(lb)(°F) and insert $T_{^\circ\text{C}} = \frac{T_{^\circ\text{F}} - 32}{1.8}$

$$C_p = 6.852 + 1.62 \times 10^{-3} T_{^\circ\text{C}} - 0.26 \times 10^{-6} T_{^\circ\text{C}}^2$$

b. $T_{^\circ\text{C}} = (T_{^\circ\text{F}} - 32)/1.8$

$$C_p = \frac{6.852 \text{ cal}}{(\text{g mol}) (^\circ\text{C})} \left| \frac{454 \text{ g mol}}{1 \text{ lb mol}} \right| \left| \frac{1 \text{ Btu}}{252 \text{ cal}} \right| \left| \frac{1 \text{ lb mol}}{29 \text{ lb}} \right| \left| \frac{1 \Delta ^\circ\text{C}}{1.8 \Delta ^\circ\text{F}} \right|$$

$$+ \frac{1.62 \times 10^{-3} \text{ cal}}{(\text{g mol}) (\Delta ^\circ\text{C}) (\Delta ^\circ\text{C})} \left| \frac{454 \text{ g mol}}{1 \text{ lb mol}} \right| \left| \frac{1 \text{ Btu}}{252 \text{ cal}} \right| \left| \frac{1 \Delta ^\circ\text{C}}{1.8 \Delta ^\circ\text{F}} \right| \left| \frac{(T_{^\circ\text{F}} - 32)^\circ\text{C}}{1.8} \right| \left| \frac{1 \text{ lb mol}}{29 \text{ lb}} \right|$$

(continue)

Solutions-Chapter-5

$$\frac{0.26 \times 10^{-6} \text{ cal}}{(\text{g mol}) (\Delta^\circ\text{C})^2 (\text{C}^\circ)^2} \left| \frac{454 \text{ g mol}}{1 \text{ lb mol}} \right| \left| \frac{1 \text{ Btu}}{252 \text{ cal}} \right| \left| \frac{1 \Delta^\circ\text{C}}{1.8 \Delta^\circ\text{F}} \right| \left| \frac{(T_{\text{F}} - 32)^2}{1.8} \right| \left| \frac{^\circ\text{C}^2}{^\circ\text{F}^2} \right| \left| \frac{1 \text{ lb mol}}{29 \text{ lb}} \right|$$

$$C_p = 0.226 + 3.118 \times 10^5 T_{\text{F}} - 2.765 \times 10^9 T_{\text{F}}^2$$

5.36

Basis: 1 lb

$$\Delta H = \int_{\Delta H_1}^{\Delta H_2} dH = \Delta H_2 - \Delta H_1 = 1510 \text{ Btu / lb}$$

$$= \int_{T_0}^{T_1} C_p dT = 1.2(1000 - T_0) + \frac{0.0050}{2}(1000^2 - T_0^2)$$

$$- 2.1 \times 10^{-6}(1000^3 - T_0^3)$$

$$= 1200 - 1.2T_0 + 0.0025 \times 10^{-6} - 2.1 \times 10^{-6} \times 10^9$$

$$= 0.0025 T_0^2 + 2.1 \times 10^{-6} T_0^3$$

$T_0 = 75^\circ\text{C}$ (Note the second and third order terms in T_0 are small so that a good approximation can be obtained using only the first order term.)

5.37

No. The enthalpy and internal energy must be changes, and each has a reference point. The calculation should be

$$\Delta \hat{U} = \Delta \hat{H} - \Delta(p\hat{V}) = (16,660 - \Delta \hat{H}_{\text{ref}}) - (P_{600} \text{ kPa} \hat{V}_{600} \text{ kPa, 283K} - P_{\text{ref}} \hat{V}_{\text{ref}})$$

If the reference for CO_2 is saturated liquid at 233K, $\Delta H_{\text{ref}} = 0 \text{ kJ/g mol}$. If the reference is at the triple point of CO_2 , the enthalpy calculated is in error.

5.38

Enthalpy change from 500 to 1000°C:

$$\Delta H = \int_{500}^{1000} C_p dT$$

$$= 6.935(1000 - 500) + \frac{6.77 \times 10^{-4}}{2}(1000^2 - 500^2) + \frac{1.3 \times 10^{-7}}{3}(1000^3 - 500^3)$$

$$= \boxed{3759 \text{ cal / gmol}}$$

Solutions-Chapter-5

5.39 ✓

$$\Delta H = 2 \int_{50+273}^{250+273} (27.32 + 0.6226 \times 10^{-2} T - 0.0950 \times 10^{-5} T^2) dT$$

From the computer solution, $\Delta H = 11,910 \text{ J}$

5.40 ✓

Computer result: $-9.707 \times 10^7 \text{ J}$

5.41 ✓

Computer result: $5.388 \times 10^3 \text{ J/g mol}$

5.42 ✓

Computer result: $2.563 \times 10^3 \text{ J/g mol}$

5.43

State 1

State 2

$T = 400 \text{ K}$

$T = 900 \text{ K}$

$p = 100 \text{ kPa}$

$p = 100 \text{ kPa}$

a. From the steam tables in SI units (interpolation required):

(1) $\Delta \hat{H}_1 = 2729.8 \text{ kJ/kg}$

(2) $\Delta \hat{H}_2 = 3763.6 \text{ kJ/kg}$

$$\Delta \hat{H} = 3763.6 - 2729.8 = 1033.8 \text{ kJ/kg}$$

$$\frac{1033.8 \text{ kJ}}{\text{kg}} \left| \frac{18 \text{ kg}}{\text{kg mol}} \right| \frac{2 \text{ kg mol}}{2} = \boxed{3.7217 \times 10^4 \text{ kJ/2 kg mol}}$$

Using the computer program "SAT - H₂O":

(1) $\Delta \hat{H}_1 = 2730.99 \text{ kJ/kg}$ (2) $\Delta \hat{H}_2 = 3760.26 \text{ kJ/kg}$

$$\Delta \hat{H} = 3760.26 - 2730.99 = 1029.27 \text{ kJ/kg}$$

$$\frac{1029.27 \text{ kJ}}{\text{kg}} \left| \frac{18 \text{ kg}}{\text{kg mol}} \right| \frac{2 \text{ kg mol}}{2} = \boxed{3.705 \times 10^4 \text{ kJ/2 kg mol}}$$

b. Using the table for the enthalpies of combustion gases:

(1) $\Delta \hat{H} = 4284 \text{ J/g mol}$

(2) $\Delta \hat{H} = 22,760 \text{ J/g mol}$

$$\Delta H = 22760 - 4284 = 1.848 \times 10^4 \text{ J/g mol} = 1.848 \times 10^4 \text{ J/kg mol}$$

$$\frac{1.848 \text{ kJ}}{\text{kg mol}} \left| \frac{2 \text{ kg mol}}{2} \right| = \boxed{3.695 \times 10^4 \text{ kJ/2 kg mol}} \quad (\text{continued})$$

Solutions-Chapter-5

c. Using the heat capacity equation for steam:

$$\Delta H = \int_{127^{\circ}\text{C} + 273}^{627^{\circ}\text{C} + 273} C_p dT = \int_{400}^{900} (33.46 + 0.6880 \times 10^{-2} T + 0.7604 \times 10^{-5} T^2 - 3.593 \times 10^{-9} T^3) dT$$

$$= 33.46 (900 - 400) + \frac{0.6880 \times 10^{-2}}{2} (900^2 - 400^2) + \frac{0.7604 \times 10^{-5}}{3} (900^3 - 400^3) - \frac{3.593 \times 10^{-9}}{4} (900^4 - 400^4)$$

$$= 20,085 \text{ J/g mol} = 20,085 \text{ kJ/kg mol}$$

$$\frac{20,085 \times 10^4 \text{ kJ}}{\text{kg mol}} \bigg| \frac{2 \text{ kg mol}}{1} = \boxed{40,170 \text{ kJ/2 kg mol}}$$

The steam tables are probably the most accurate value.

5.44

Basis: 5 ft³

Vapor = 4 ft³, Liquid = 1 ft³

Steam tables: Sat'd steam at 1000 psia

$$\hat{V}_v = 0.44596 \frac{\text{ft}^3}{\text{lb}}$$

$$\hat{V}_l = 0.02159 \frac{\text{ft}^3}{\text{lb}}$$

lb

mass fr.

$$m_l = \frac{1 \text{ ft}^3}{0.02159 \text{ ft}^3} \bigg| \frac{\text{lb}}{1} = 46.32$$

46.32

0.838

$$m_v = \frac{4 \text{ ft}^3}{0.44596 \text{ ft}^3} \bigg| \frac{\text{lb}}{1} = 8.97$$

8.97

0.162

$m_t =$

55.29

1.000

$$\boxed{\text{Quality} = 0.162}$$

5.45

We will use the steam tables for this problem.

Basis: 1 lb of H_2O at $60^\circ F$

From steam tables (ref. temp. = 32°F):

$\hat{H} = 28.07 \text{ Btu/lb}$ at 60°F

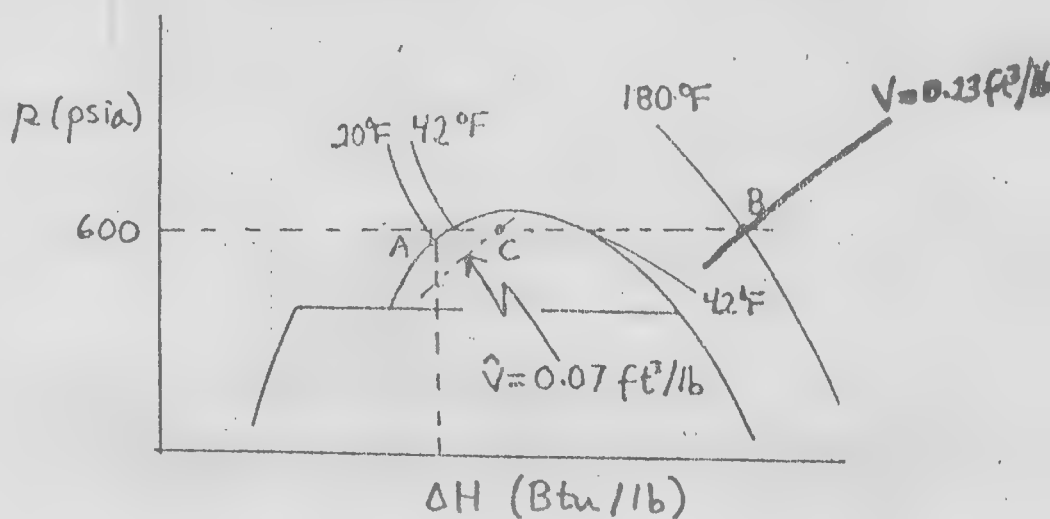
$\hat{H} = 1604.5 \text{ Btu/lb}$ at 1150°F and 240 psig (254.7 psia)

$$\Delta \hat{H} = (1604.5 - 28.07) = 1576.4 \text{ Btu/lb}$$

$$\Delta H = 1576(8.345) = 13,150 \text{ Btu/gal}$$

Note: The enthalpy value which has been used for liquid was taken from the steam tables for the saturated liquid under its own vapor pressure. Since the enthalpy of liquid water changes negligibly with pressure, no loss of accuracy is encountered for engineering purposes if the initial pressure on the water is not stated.

5.46



- a-1: $\hat{V} \cong 0.23 \text{ ft}^3/\text{lb}$
a-2: gas
b-1: 42°F
b-2: mixture of liquid and vapor

5.47

The volume of the wire is $\left(\frac{\pi D^2}{4}\right) 5.5 = \pi \frac{(0.25)^2}{4} (5.5) = 0.27 \text{ cm}^3$. The density of Al is 19.35 g/cm^3 , so $19.35(0.27) = 5.22 \text{ g}$ or 0.194 g mol Al . From Perry, $C_p = 20.0 + 0.0135T$ (T in K, C_p in $\text{J/(g mol)}(^{\circ}\text{C})$) and $\Delta H_{\text{fusion}} = 10,670 \text{ J/g mol}$ at 660°C .

$$\Delta H = 0.194 \left[\int_{25+273}^{660+273} (20.0 + 0.0135T) dT + 10,670 \right] = 5560 \text{ J}$$

$$5560(2.773 \times 10^{-7}) = 1.54 \times 10^{-3} \text{ kWh}$$

5.48 Basis: 1 g mol SO_2 (g) at 538°C

$$\Delta H = \int_{538}^{-5} (33.97 + 2.856 \times 10^{-2} T_{\text{C}} - 8.79 \times 10^{-6} T_{\text{C}}^2) dT$$

$$+(-24,940) + \int_{-5}^{-75.5} (1.28) dT + (-7,401) + \int_{-75.5}^{-101} (0.958) dT$$

$$= \left[33.97(-5 - 538) + \frac{2.856 \times 10^{-2}}{2} ((-5)^2 - (538)^2) \right.$$

$$\left. - \frac{8.79 \times 10^{-6}}{3} [(-5)^2 - (538)^3] - 24,940 + (1.28)[(-75.5) - (-5)] \right.$$

$$\left. - 7,401 + (0.958)[(-101) - (-75.5)] \right] = -54,578 \text{ J}$$

5.49

Basis: 3 kg H_2O

The initial conditions are obtained from the SI steam tables for saturated liquid. Enthalpy is a function of the temperature and pressure, but the effect of pressure on liquid water under these conditions is negligible. Therefore the enthalpy of water at 300K and 101.3 kPa can be approximated by the enthalpy of saturated water at the same temperature but at the vapor pressure of 3.536 kPa .

The final conditions are presumably a state in which water is all vapor. A check of the steam tables shows this assumption to be true.

(continued)

At

T(K)	p(kPa)	$\Delta\hat{H}$ (kJ/kg)
300	3.536	111.7
800	1500	3384.3

The enthalpy change is

$$\Delta H = \frac{3 \text{ kg}}{\text{kg}} (3384.3 - 111.7) \text{ kJ} = 9817.8 \text{ kJ}$$

5.50

Steady state flow process, no reaction

The energy balances reduces to $\Delta H = 0$ for this process. At 700 kPa saturated

$$(438.1\text{K}) \quad \Delta\hat{H}_L = 696.7 \text{ kJ/kg}$$

$$\Delta\hat{H}_v = 2763.1 \text{ kJ/kg}$$

Let x = vapor fraction

$$(1-x)(696.7) + x(2763.1) = 2725.4$$

$$x = 0.98$$

5.51 Basis: 30 m³ at 101.3 kPa and 1100KUse $pV = nRT$ to calculate the number of moles

$$n = \frac{pV}{RT} = \frac{101.3 \text{ kPa} \cdot 30 \text{ m}^3}{1100\text{K}} \cdot \frac{\text{kg mol K}}{8.314 \text{ kPa}(\text{m}^3)} \cdot \frac{1000 \text{ gmol}}{1 \text{ kg mol}}$$

$$n = 332.3 \text{ gmol}$$

Compound	%	g mol	$\Delta\hat{H}$ (J/g mol)		ΔH (J)	
			300K	1100K	Final	Initial
O ₂	6.2	20.6	790	26,940	16,274	554,964
H ₂ O	1.0	3.3	905	31,011	2987	102,336
CO ₂	12.3	40.9	986	39,802	40,327	1,627,902
N ₂	80.5	267.5	786	25,472	210,255	6,813,760
	100.0	332.3			269,843	9,098,963

$$\Delta H = \Delta H_{\text{final}} - \Delta H_{\text{initial}} = -8829 \text{ kJ}$$

Solutions-Chapter-5

5.52

Use $\Delta H = n \int_{50}^{550} C_p dt$ for each gas where n is the number of moles,
and add the ΔH 's.

Basis; 1 kg mol gas

Methane:

$$\begin{aligned}\Delta H_{M1} &= (0.8)(1000) \left[8.20(550 - 50) + 1.307 \times 10^{-2} \left[\frac{(550)^2 - (50)^2}{2} \right] \right. \\ &\quad \left. + 0.0875 \times 10^{-5} \left[\frac{(550)^3 - (50)^3}{3} \right] - 2.630 \times 10^{-9} \left[\frac{(550)^4 - (50)^4}{4} \right] \right] \\ &= (6146 \text{ cal/g mol})(800 \text{ g mol}) = 4.917 \times 10^6 \text{ cal}\end{aligned}$$

Ethane:

$$\begin{aligned}\Delta H_E &= (0.2)(1000) \left[11.80(550 - 50) + 3.326 \times 10^{-2} \left[\frac{(550)^2 - (50)^2}{2} \right] \right. \\ &\quad \left. - 1.390 \times 10^{-5} \left[\frac{(550)^3 - (50)^3}{3} \right] + 1.740 \times 10^{-9} \left[\frac{(550)^4 - (50)^4}{4} \right] \right] \\ &= (10,158 \text{ cal/g mol})(200 \text{ g mol}) = 2.032 \times 10^6 \text{ cal}\end{aligned}$$

$$\Delta H = \Delta H_M + \Delta H_E = (6.948 \times 10^6 \text{ cal})(4.184) = \boxed{2.907 \times 10^7 \text{ J/kg mol}}$$

5.53

Basis: 1 lb mol

6.00 lb mol gaseous H_2O , 4.00 lb mol CO_2

Heated from 60°F (15.6°C) to 600°F (315.6°C)

From appendix E for H_2O :

$$\Delta \hat{H} = \int_{15.6}^{315.6} (33.46 + 0.6880 \times 10^{-2} T + 0.7604 \times 10^{-5} T^2 - 3.593 \times 10^{-9} T^3) dT$$

(continued)

$$= 33.46 (315.6 - 15.6) + \frac{0.6880 \times 10^{-2}}{2} (315.6^2 - 15.6^2) \\ + \frac{0.7604 \times 10^{-5}}{3} (315.6^3 - 15.6^3) - \frac{3.593 \times 10^{-9}}{4} (315.6^4 - 15.6^4)$$

$$\Delta \hat{H} = 1.045 \times 10^4 \text{ J/g mol}$$

$$\frac{1.045 \times 10^4 \text{ J}}{\text{g mol}} \left| \frac{454 \text{ g mol}}{\text{lb mol}} \right| \frac{9.484 \times 10^{-4} \text{ Btu}}{\text{J}} = 4.499 \times 10^3 \text{ Btu/lb mol}$$

For CO_2 in Btu/(lb mol)(°F):

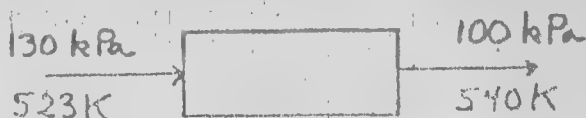
$$\Delta \hat{H} = \int_{60}^{600} (8.448 + 0.5757 \times 10^{-2} T - 0.2159 \times 10^{-5} T^2 + 0.3059 \times 10^{-9} T^3) dT \\ = 8.448 (600 - 60) + \frac{0.5757 \times 10^{-2}}{2} (600^2 - 60^2) - \frac{0.2159 \times 10^{-5}}{3} (600^3 - 60^3) \\ + \frac{0.3059 \times 10^{-9}}{4} (600^4 - 60^4)$$

$$\Delta \hat{H} = 5.442 \times 10^3 \text{ Btu/lb mol}$$

$$\Delta H = (4.499 \times 10^3 \text{ Btu/lb mol}) (6.00 \text{ lb mol}) + (5.442 \times 10^3 \text{ Btu/lb mol}) (4.00 \text{ lb mol})$$

$$\boxed{\Delta H = 4.88 \times 10^4 \text{ Btu}}$$

5.54



If you use Steam Tables, interpolation is required.

		$\hat{U}$ (kJ/kg)		
		500	523	550
P {	101.3	2698.1		2774.3
	200.0	2695.2		2772.2
	p = 130	2697.1		2773.7
		$\hat{U}$		
		2732.3		
		$\left. \begin{array}{l} T = 540 \\ p = 100 \end{array} \right\} \hat{U} = 2759.1$		
$\Delta \hat{U} = 2759.1 - 2732.3 =$		$\boxed{26.8 \text{ kJ/kg}}$		

5.55 Basis: 100 mol gas

2.55	Basis: 100 mol gas	Comp.	mol		
		CO	68		
		H ₂	30		
		CO ₂	2		
			100		
			$\Delta \hat{H}$ (J/g mol) relative to 0°C and 1 atm		
			CO	H ₂	CO ₂
25°C =	298 K		728	718	912
	1500 K		39,576	36,994	62,676
1400°C =	1673 K		45,723	42,724	72,896
	1750 K		48,459	45,275	77,445

Basis: 1000 m³ at 101 kPa and 1673 K

$$\frac{1000 \text{ m}^3}{1673 \text{ K}} \left| \frac{298 \text{ K}}{22.4 \text{ m}^3} \right| \frac{1 \text{ kg mol}}{22.4 \text{ m}^3} = 7.95 \text{ kg mol}$$

Calculation of ΔH :

	kg mol	$\Delta \hat{H}$ (kJ/kg mol)	ΔH (kJ)
CO	7.95 (.68)	-44,995	-243,243
H ₂	7.95 (.30)	-42,010	-100,194
CO ₂	7.95 (.02)	-71,984	-11,445
			$\boxed{-354,882}$

5.56

$^{\circ}\text{K}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$	
423	150.0	302	vapor
353.3	80.1	176	↓ satd vapor
278.7	5.5	42	→ satd liquid ↓ satd liquid
253.0	-20.0	-4	

Basis: 1 g mol

From Table D.1 in the Appendix.

Benzene properties:

Mol. wt.	78.11	Boiling point	353.26 K
Melting point	278.69 K	$\Delta H_{\text{vaporization}}$	30.76 kJ/g
ΔH_{fusion}	9.84 kJ/g mol		

K	$^{\circ}\text{C}$
423	150
353.26	80.11
278.69	5.54
253	-20

Heat Capacity Equation Coefficients:

	a	b	c	d
Benzene(g)	74.06	32.95×10^{-2}	-25.20×10^{-5}	77.57×10^{-9}
Benzene(l)	62.55	23.9×10^{-2}		

The C_p equation is in $^{\circ}\text{C}$ hence the limits on integration should be in $^{\circ}\text{C}$.

$$\int_{423}^{353} (74.06 + 32.95 \times 10^{-2} T - 25.20 \times 10^{-5} T^2 + 77.57 \times 10^{-9} T^3) dT =$$

$$-11,790 \text{ J/g mol}$$

Condensation

$$\Delta H_2 = -3.076 \times 10^4 \text{ J/g mol}$$

Liquid

$$\Delta H_3 = \int_{353.26}^{278.69} (62.55 + 23.4 \times 10^{-2} T) dT = -10,180 \text{ J/g mol}$$

(con

Fusion

$$\Delta H_4 = -9.84 \times 10^3 \text{ J/g mol}$$

Solid

From Perry, 5th edition:	$C_p(\text{cal}) / (\text{g})(^\circ\text{C})$	$C_p(\text{J} / (\text{g mol})(^\circ\text{C}))$
0°C	0.375	12.3
-50°C	0.299	97.7

If a linear relationship exists between C_p and T ,

$$C_{pav} = 119 \text{ J/(g mol)} (^\circ\text{C}) \quad -11,790$$

$$\Delta H_5 = \int_{-50}^{-20} (119) dT = -3034 \text{ J/g mol} \quad -30,760$$

$$-10,180$$

$$\text{Overall, } \Delta H = \sum_{i=1}^5 \Delta H_i = -65,604 \text{ J/g mol} \quad -9,840$$

$$-3,034$$

$$\frac{-65,604 \text{ J/g mol}}{78.11 \text{ g/mol}} \times \frac{1000 \text{ g}}{\text{kg}} = \boxed{-8.40 \times 10^5 \text{ J/kg}} \quad -65,604$$

5.57

Vapor pressure equation:

$$\log p = \frac{-6160}{T} + 8.10, \quad (T \text{ in K})$$

Clausius-Clapeyron equation:

$$\frac{d(\log p)}{dT} = \frac{\Delta \hat{H}_v}{2.303 RT^2}$$

Differentiate the first equation:

$$\frac{d(\log p)}{dT} = \frac{d}{dT} \left[\frac{-6160}{T} + 8.10 \right] = \frac{+6160}{T^2}$$

Equate the two equations:

$$\frac{\Delta \hat{H}_v}{2.303 RT^2} = \frac{6160}{T^2}$$

(continued)

$$\Delta \hat{H}_v = (6160)(2.303)(R)$$

$$= (6160)(2.303) \left\{ \begin{matrix} 1.987 \\ 8.314 \end{matrix} \right\}$$

28,190 cal/g mol
28,190 Btu/lb mol
117,950 J/g mol

5.58

$$(a) \quad \ln \left[\frac{p_2^*}{p_1^*} \right] = \frac{-\Delta \hat{H}_v}{R} \left[\frac{1}{T_2} - \frac{1}{T_1} \right] \Rightarrow \ln \left[\frac{100}{28} \right] = \frac{-\Delta \hat{H}_v}{8.314} \left(\frac{1}{333} - \frac{1}{283} \right)$$

$$\Delta \hat{H}_v = 19,950 \text{ J/g mol}; \quad @30^\circ\text{C} = 303\text{K}$$

$$\ln \left[\frac{p^*}{28} \right] = \left[\frac{-4767.3}{1.987} \right] \left[\frac{1}{303} - \frac{1}{283} \right] \text{ so } p^* = \boxed{48.99 \text{ mm Hg}}$$

$$\text{Basis: } 150 \text{ g or } \frac{150}{96} = 1.563 \text{ g mol}$$

$$\text{We need } 1.563(19,950) = \boxed{31,180 \text{ J}}$$

$$(b) \quad p_{60^\circ\text{C}}^* = 100 \text{ mm Hg} \quad y_A = \frac{p^*}{p_t} = \frac{100}{760(2)} = \boxed{0.0658}$$

$$\text{Basis: } 25 \text{ g or } \frac{25}{96} = 0.260 \text{ g mol}$$

$$\frac{0.260}{(F)(t) + 0.260} = 0.0658 \quad \text{so} \quad F = 3.69 \text{ g mol}$$

$$F = \frac{p \hat{V}}{RT} = \frac{2(100)}{(82.057)(333)} = 0.0073 \text{ g mol/min}$$

$$\text{Thus } 3.691 = Ft \quad \text{and} \quad t = \frac{3.691}{0.0073} = \boxed{504 \text{ min}}$$

$$(c) \quad \text{At } p_t = 1 \text{ atm: } (1)(0.0658) = p^* @ T_{\text{DP}} = 50.008 \text{ mm Hg}$$

$$\text{so } \ln \left[\frac{50.008}{28} \right] = \frac{19,950}{8.314} \left[\frac{1}{T_K} - \frac{1}{283} \right]$$

$$T_K = 303.8 = \boxed{30.8^\circ\text{C}}$$

5.59

Basis: liquid water at 32°F and 1 atm

$$a. \quad \Delta H = 3(\hat{\Delta H}_{300^\circ\text{F}, 1 \text{ atm}} - \hat{\Delta H}_{32^\circ\text{F}, 1 \text{ atm}}) = 3(1192 - 0) = \boxed{3576 \text{ Btu}}$$

b. Basis: liquid water at 40°F and 60 psia

$$\hat{\Delta H}_{32^\circ\text{F}, 60 \text{ psia}} = 0 \quad \Delta H = 3(11192 - 0) = \boxed{3576 \text{ Btu}}$$

c. Basis: liquid water 40°F and 60 psia

$$\Delta H = (\hat{\Delta H}_{300^\circ\text{F}, 60 \text{ psia}} - \hat{\Delta H}_{40^\circ\text{F}, 60 \text{ psia}}) = (1181.4 - 8.05) \\ = \boxed{1173.4 \text{ Btu}}$$

d. Basis: water-steam mixture of 60% quality

State		$\hat{\Delta H}$, Btu/lb
1	60% steam - 40% water at 300°F; sat'd steam	1179.7
2	80% steam - 20% water at 300°F; water	269.6

$$\Delta \hat{H} = \hat{\Delta H}_2 - \hat{\Delta H}_1$$

$$\hat{\Delta H}_2 = (0.80)(1179.7) + (0.20)(269.6) = 998 \text{ Btu/lb}$$

$$\hat{\Delta H}_1 = (0.60)(1179.7) + (0.40)(269.6) = 816 \text{ Btu/lb}$$

$$\text{Enthalpy change needed} = \Delta \hat{H}$$

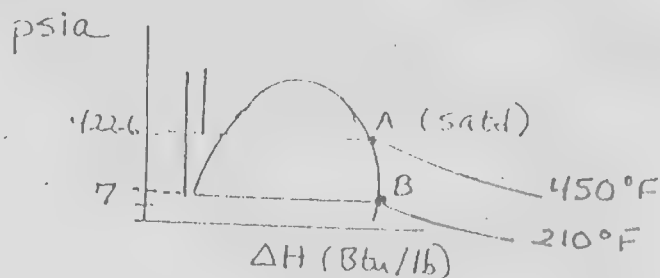
$$\Delta \hat{H} = \hat{\Delta H}_2 - \hat{\Delta H}_1 = \boxed{182 \text{ Btu/lb}}$$

c. Basis: steam at 500°F and 120 psia

$$\Delta \hat{H} = \hat{\Delta H}_2 - \hat{\Delta H}_1 = 312.5 - 1276.7 = \boxed{-964.2 \text{ Btu/lb}}$$

$$f. \quad \Delta \hat{H} = \hat{\Delta H}_2 - \hat{\Delta H}_1 = 487.8 - 1276.7 = \boxed{788.9 \text{ Btu/lb}}$$

5.59



Data from text

$$\Delta H_A = 1205.0$$

 ΔH_B use tables in pocket210°F

5 psia	<u>200°F</u> 1148.3	<u>250°F</u> 1171.1	a. Enthalpy decrease
7 psia	1146.7	1170.2	

$$\hat{V}_A = 1.0451 \text{ ft}^3/\text{lb}$$

V_B	78.17	84.24	b. volume goes up
	38.88	41.96	

(h) 40 psia and 267.24°F
sat steam/sat liquid70 psia/302°F
liquid70 psia/304°F
superheated steam

depending on heat supply

(i) 2.5 ft³ tank of water @ 160 psia and 363.5°F. @ 160 psia 6363.5 total volume is occupied by sat steam

$$\hat{V}_{\text{steam}} = 2.834 \text{ ft}^3/\text{lb} \Rightarrow m_{\text{steam}} = \frac{2.5}{2.834} = 0.88 \text{ lb}$$

$$\hat{V}_{\text{Liq/water}} = 0.0182 \text{ ft}^3/\text{lb} \Rightarrow m_{\text{water}} = (1 - m_{\text{steam}})$$

$$V_{\text{water}} = \frac{2.5}{2.834} \times 0.0182 = \boxed{0.016 \text{ ft}^3}$$

$$V_{\text{steam}} = 2.5 - 0.016 = 2.49 \text{ ft}^3$$

(continued)

Solutions-Chapter-5

Of 5 lb H_2O assume x lb is sat steam $(5-x)$ lb is sat. water

$$x(2.834) + (5-x)(0.0182) = 2.5$$

$$\Rightarrow x(2.834 - 0.0182) = 2.5 - 5(0.0182)$$

$$\Rightarrow x = \frac{2.5 - .0910}{2.816}$$

$$x = 0.86 \text{ lb}$$

Yes, it is possible

(k) Enthalpy of 10 lb steam @ 100 psia = 9000 Btu

Enthalpy/lb steam @ 100 psia = 900 Btu

$$\Delta \hat{H}_{\text{steam}} @ 100 \text{ psia} = 1187.3 \text{ Btu}$$

$$\Delta \hat{H}_{\text{water}} @ 100 \text{ psia} = 298.43 \text{ Btu}$$

Let x be fraction of steam

$(1-x)$ is fraction of water

$$(1187.3)x + (1-x) 298.43 = 900$$

$$x(1187.3 - 298.43) = 900 - 298.43 \quad x = \frac{601.57}{888.87} = 0.68$$

or 68%

5.60

Basis: 10 lb steam @ 300 psia and 480°F

$$\left. \begin{array}{l} \Delta \hat{H} = 1246.6 \text{ Btu/lb} \\ \hat{V} = 1.7164 \text{ ft}^3/\text{lb} \end{array} \right\} \text{superheated initial}$$

After cooling to 30 psia, the steam is saturated and liquid forms. Ignore the volume of the liquid. Final conditions are 30 psia and 17.164 ft³ for the residual vapor

$$\Delta \hat{H}_L = 218.83 \text{ Btu/lb} \quad \hat{V}_L = 0.0170 \text{ ft}^3/\text{lb}$$

$$\Delta \hat{H}_V = 1164.0 \text{ Btu/lb} \quad \hat{V}_V = 13.763 \text{ ft}^3/\text{lb}$$

$$\frac{1 \text{ lb} \left| \frac{17.164 \text{ ft}^3}{13.763 \text{ ft}^3} \right|}{13.763 \text{ ft}^3} = 1.25 \text{ lb vapor}$$

(continued)

We could now correct for the liquid volume, but will not. The final state is

$$\Delta H = 1.25(1164.0) + 8.75(218.8) = 3320 \text{ Btu}$$

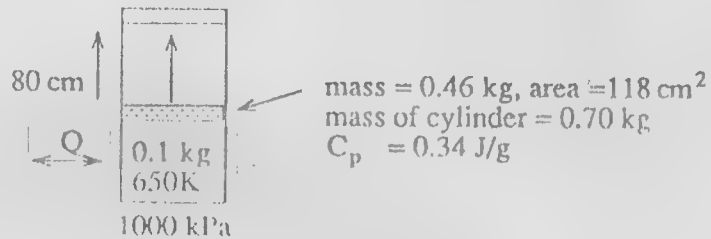
The initial state is 12,466 Btu

$$Q = \Delta H = 3320 - 12,466 = \boxed{-9,096 \text{ Btu}}$$

(heat removed)

The final T @ 30 psia saturated is $\boxed{250.34^\circ\text{F}}$

5.61



Final pressure = 700 kPa

Batch process, unsteady state

(a) The work can be calculated from $\int p dV$ if some assumptions are made about the process (path taken by the gas). However, no information is given about the process other than "slowly". Assume the work done (against the atmosphere) is carried out at constant pressure. Then

$$W = -p\Delta V$$

Initial conditions

$V = 0$ at the start of the expansion

(d) Change in volume of the system

$$\text{added } V = \frac{(80 \text{ cm})(118 \text{ cm}^2)}{(100 \text{ cm})^3} \left| \frac{1 \text{ m}^3}{(100 \text{ cm})^3} \right| = 0.00944 \text{ m}^3$$

$$W = -\frac{101.3 \text{ kPa} \cdot 0.00944 \text{ m}^3}{(1 \text{ kPa})(\text{m}^3)} \left| \frac{1 \text{ J}}{(1 \text{ kPa})(\text{m}^3)} \right| = \boxed{-9.56 \text{ J}}$$

(work done by system)

(b) No information is given about the heat transfer between the system and
(c) the surroundings, and final temperature depends on the heat transferred.

5.62 Unsteady state, isothermal process at 25°C
Basis: 1 kg CO₂



	$p_1 = 550 \text{ kPa}$	$p_2 = 3500 \text{ kPa}$
	$T_1 = 25^\circ\text{C}$	$T_2 = 25^\circ\text{C}$
From CO ₂ {	$\hat{V}_1 = 0.10 \text{ m}^3/\text{kg}$	$\hat{V}_2 = 0.0125 \text{ m}^3/\text{kg}$
chart {	$\Delta\hat{H} = 205 \text{ kJ/kg}$	$\Delta\hat{H}_2 = 170 \text{ kJ/kg}$

Energy balance

$$\Delta E = \Delta(U + P + K) = Q + W - \Delta(\hat{H} + P + K)$$

$$\Delta U = Q + W = \Delta H - \Delta(pV) \text{ so } Q = \Delta H - \Delta(pV) - W$$

$$\Delta H = (170 - 205)(1) = -35 \text{ kJ}$$

$$W = -4.106 \text{ kJ}$$

$$\Delta(pV) = \left[\frac{3500 \text{ kPa}}{1 \text{ kg}} \left| \frac{0.0125 \text{ m}^3}{\text{kg}} \right| - \frac{550 \text{ kPa}}{1 \text{ kg}} \left| \frac{0.10 \text{ m}^3}{\text{kg}} \right| \right]$$

$$\left[\frac{10^3 \frac{\text{N}}{\text{m}^2}}{1 \text{ kPa}} \left| \frac{1 \text{ J}}{1(\text{N})(\text{m})} \right| \right] = -11.25 \text{ kJ}$$

$$Q = -4.106 + (-35) - (-11.25) = \boxed{27.86 \text{ kJ/kg CO}_2 \text{ (removed)}}$$

Handwritten notes:

$$\Delta E = Q + W$$

$$\Delta U + \Delta P + \Delta K = Q + W$$

$$\Delta H - \Delta(pV) = Q + W$$

$$Q =$$

5.63

A closed vessel having a volume of 100 ft³ is filled with saturated steam at 265 psia. At some later time, the pressure has fallen to 1000 psia due to heat losses from the tank. Assuming that the contents of the tank are in an equilibrium state, how much heat was lost from the tank?

This is an unsteady state closed process. The energy balance reduces to

$$\Delta E = Q - \dot{W} = \Delta U + \Delta P + \Delta K$$

$$Q = \Delta U = \Delta U_2 - \Delta U_1 = \Delta H - \Delta(pV) = \Delta H - (p_2 V_2 - p_1 V_2)$$

where 2 is the final state and 1 is the initial state.

(continued)

From the steam tables. Get the initial amount of steam and use as the basis: $100 \left(\frac{1}{1.742} \right) = 57.4 \text{ lb}$

$$\hat{V}_1 = 1.742 \frac{\text{ft}^3}{\text{lb}}; \Delta H_1 = 1201.7 \frac{\text{Btu}}{\text{lb}} \left| \frac{\text{lb}}{1.742 \text{ ft}^3} \right| \frac{100 \text{ ft}^3}{1} = 6.898 \times 10^4 \text{ Btu}$$

At 100 psia, some of the steam condenses to water so that ΔH is the sum of the $\Delta H_{\text{liquid}} + \Delta H_{\text{vapor}}$. $\hat{V}_{\text{liquid}} = 0.0177 \text{ ft}^3 / \text{lb}$, $\hat{V}_{\text{vapor}} = 4.433 \text{ ft}^3 / \text{lb}$

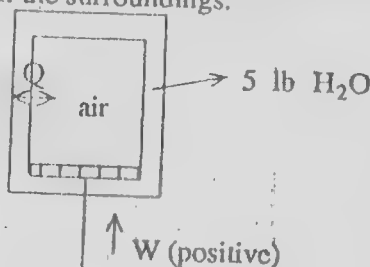
$$x(0.0177) + (1-x)(4.433) = 1.742 \quad x = 0.6095 \text{ (liquid)}$$

$$\Delta H_2 = 0.6095(298.43) + 0.3905(1187.3) = 645.5$$

$$Q = 645.5(57.4) - 6.848 \times 10^4 = \boxed{-3.19 \times 10^4}$$

5.64

This is an unsteady state process in a closed system, or a closed system and a closed surroundings. From the latter viewpoint $\Delta U = Q + W$ where Q is the heat transfer to the water from the surroundings.



For the system of the air

$$Q + W = \Delta E = \Delta U + \Delta P + \Delta K = \Delta H - \Delta(pV)$$

For the water:

$$Q = \Delta H - \Delta(pV) \text{ but } \Delta(pV) \text{ is negligible for liquid water so that}$$

$$Q = \Delta H = 5 \int_T^{T+2.3} C_p dT = 5 C_p (T + 2.3 - T) \text{ for constant } C_p.$$

$$C_p = 8.0 \frac{\text{Btu}}{(\text{lb mol})(^\circ\text{F})} \quad (\text{or use the steam tables})$$

$$Q = 8.0 \frac{\text{Btu}}{(\text{lb mol})} \left| \frac{2.3^\circ\text{F}}{1} \right| \left| \frac{1 \text{ lb mol H}_2\text{O}}{18 \text{ lb H}_2\text{O}} \right| \frac{5 \text{ lb H}_2\text{O}}{1} = 5.11 \text{ Btu}$$

(continued)

Solutions-Chapter-5

Q is removed from the air, so for the system comprised of the air, $Q = -5.11$ Btu.

For the system of the air

$$W = \frac{12,500(\text{ft})(\text{lb}_f) \left| \frac{0.0012854 \text{ Btu}}{1(\text{ft})(\text{lb}_f)} \right|}{1(\text{ft})(\text{lb}_f)} = 16.07 \text{ Btu}$$

W is positive when the surroundings do work on the system of the air.

Basis: 3 ft^3 air

$$\Delta U = -5.11 \text{ Btu} + 16.07 \text{ Btu} = \boxed{10.96 \text{ Btu}}$$

5.65 The system initially is like the figure, but since $p_A > p_B$, the plug moves



to the right. The energy balance here is $Q + W = \Delta E = \Delta U + \Delta P + \Delta K$. Since $Q = 0$ and $W = 0$, ΔU must be 0. ΔP and $\Delta K = 0$. Thus, the change in internal energy of the sum of gases A and B equals the change in the internal energy of the cylinder.

5.66 The energy balance reduces to $Q + W = \Delta E = \Delta U + \Delta P + \Delta K$

$$Q = 0, W = 0, \Delta P = 0, \Delta K = 0 \text{ hence } \Delta U = 0.$$

5.67 Steps 1, 2, 3 and 4

Get the needed properties from the CO_2 chart or tables. Let m be the mass of CO_2 in the cylinder at the final state, $\hat{V}$ is the specific volume, ΔH_2 is the enthalpy of the CO_2 at the end of the filling, and ΔH_1 is the enthalpy of the CO_2 at the beginning of the filling.

$$\text{At } 200 \text{ psia, } 40^\circ\text{F, } \Delta \hat{H} \approx 153 \text{ Btu/lb}$$

Step 5 Basis: 3 ft^3 of CO_2 @ 200 psia, 40°F

System: CO_2 in the cylinder

Unknowns: V_{CO_2} , m_{CO_2}

(continued)

Solutions-Chapter-5

Steps 6, 7, 8 and 9

$$\Delta E = \Delta U = Q + W \quad Q = W = 0 = \Delta H - \Delta(pV)$$

hence

$$\Delta H - \Delta(pV) = 0 \text{ if use Amer. Engr. units}$$

$$\Delta H = \Delta \hat{H}_2 m_2 - \Delta \hat{H}_1 m_1 = \Delta(pV)$$

$$m_2 \Delta \hat{H}_2 - m_1 \Delta \hat{H}_1 = \underbrace{p_2 \hat{V}_2}_{200} - \underbrace{p_1 \hat{V}_1}_0$$

Could use $pV = znRT$ or use the charts and trial and error. We need to find the temperature at which the internal energy of CO_2 is the same as its enthalpy at 40°F . From enthalpy - pressure chart, solve above equation by trial and error. If you had SI tables you could get ΔU values directly.

H_{syst} (Chart) (Btu / lb)	$\hat{V}$ (Chart) (ft ³ / lb)	H_{syst} (calc.) (Btu / lb)
140	0.6	175
180	0.7	179

a. Final condition

$$H_{\text{syst}} = 180 \text{ Btu/lb}, \quad \hat{V}_2 = 0.7 \text{ ft}^3/\text{lb}$$

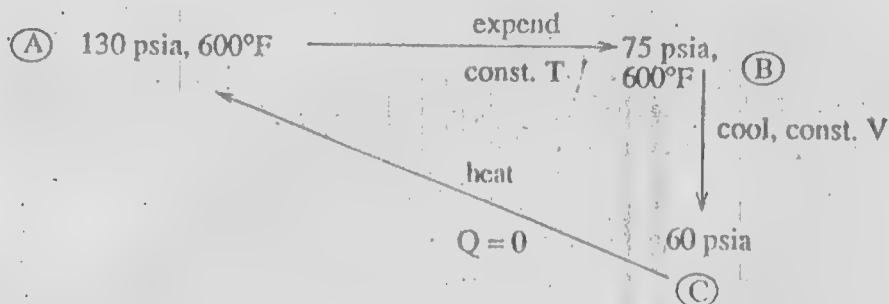
$$T = 150^\circ\text{F}$$

b. lb of CO_2 in the tank

$$m_{\text{CO}_2} = 3 \text{ ft}^3 / 0.7 (\text{ft}^3 / \text{lb}) = 4.3 \text{ lb}$$

5.68

Closed system; hence $Q + W = \Delta E = \Delta U$



Basis: 1 lb steam

$$\textcircled{A} \rightarrow \textcircled{B} : \quad \Delta H = 1329.6 - 1326.1 = 3.5 \text{ Btu/lb}$$

$$\Delta U = \Delta H - \Delta(pV) =$$

(continued)

$$= 3.5 - \left[\frac{75 \text{ lb}_f}{\text{in}^2} \left| \frac{8.319 \text{ ft}^3}{\text{lb}} - \frac{130 \text{ lb}_f}{\text{in}^2} \left| \frac{4.760 \text{ ft}^3}{\text{lb}} \right| \right] \left[\frac{144 \text{ in}^2}{\text{ft}^2} \left| \frac{1 \text{ Btu}}{778 \text{ (ft) (lb}_f\text{)}} \right| \right]$$

$$= 3.5 - .95 = \boxed{2.5 \text{ Btu/lb}} \quad Q = ? \quad W = ?$$

$W = -\int p dV$ but pV relation is not known.

Ⓐ → Ⓑ : $\boxed{W = 0}$ (at constant volume)

$$\Delta H = 1232.7 - 1329.6 = \boxed{-96.9 \text{ Btu/lb}}$$

$$\Delta U = -96.9 - \left[\frac{60 \text{ lb}_f}{\text{in}^2} \left| \frac{8.319 \text{ ft}^3}{\text{lb}} - \frac{75 \text{ lb}_f}{\text{in}^2} \left| \frac{8.319 \text{ ft}^3}{\text{lb}} \right| \right] \left[\frac{144 \text{ in}^2}{\text{ft}^2} \left| \frac{1 \text{ Btu}}{778 \text{ (ft) (lb}_f\text{)}} \right| \right] = -73.8 \text{ Btu/lb}$$

$$Q = \Delta \hat{U} = \boxed{-73.8 \text{ Btu/lb}}$$

Ⓑ → Ⓐ : $Q = 0$ so $W = \Delta U = \Delta H - \Delta(pV)$

$$\Delta H = 1326.1 - 1232.7 = 93.4 \text{ Btu/lb}$$

$$\Delta(p\hat{V}) = \left[\frac{130 \text{ lb}_f}{\text{in}^2} \left| \frac{4.760 \text{ ft}^3}{\text{lb}} - \frac{60 \text{ lb}_f}{\text{in}^2} \left| \frac{8.319 \text{ ft}^3}{\text{lb}} \right| \right] \left[\frac{144 \text{ in}^2}{\text{ft}^2} \left| \frac{1 \text{ Btu}}{778 \text{ (ft) (lb}_f\text{)}} \right| \right] = 22.15 \text{ Btu/lb}$$

$$W = 93.4 - 22.15 = \boxed{71.3 \text{ Btu/lb}}$$

5.69 Closed system, unsteady state; system is both tanks together

Basis: 1 m^3 dry steam, 350 K, 40 kPa equivalent to $\frac{1 \text{ kg}}{4.003} \equiv 0.25 \text{ kg}$

a. $W = 0$ because the system boundary is fixed.

b. The energy balance reduces to $Q = \Delta U$

(continued)

Solutions-Chapter-5

Initial Data

$$\hat{V} = 4.005 \text{ m}^3 / \text{kg}$$

$$\Delta \hat{H} = 2638.2 \text{ kJ/kg}$$

$$\Delta \hat{U} = 2478.0 \text{ kJ/kg}$$

$$T = 350\text{K}$$

Final Data

$$V = 2 \text{ m}^3$$

$$\hat{V} = \frac{2 \text{ m}^3}{0.25 \text{ kg}} = 8.01 \text{ m}^3 / \text{kg}$$

$$T = 350\text{K}$$

At $\hat{V} = 8.044$, $T = 350\text{K}$, $\Delta \hat{H} = 2641.4$ and $\Delta \hat{U} = 2480.6 \text{ kJ/kg}$

$$\hat{Q} = 2480.6 - 2478.0 = 2.6 \text{ kJ/kg}$$

$$(2.6)(0.25) = \boxed{0.65\text{kJ}}$$

5.70

Use a CO_2 chart or tables (note $\Delta \hat{H}$ or $\Delta \hat{U}$ may have different reference points in different sources of data).

$$Q + W = \Delta U = \Delta H - \Delta(pV)$$

The system is the gas.

Basis: 0.37 lb CO_2

$$Q = -40 \text{ Btu}$$

From the CO_2 chart:

$$\Delta \hat{H}_{\text{out}} - \Delta \hat{H}_{\text{in}} = (58 - 175) = -117 \text{ Btu/lb}$$

$$\Delta(p\hat{V}) = \frac{1000 (\text{lb}_f) \sim 0 \text{ in.}^3}{\text{in.}^2} \left| \frac{14.7 \text{ lb}_f}{\text{in.}^2} \right| \frac{9.8 \text{ ft}^3}{\text{lb}_m} \left| \frac{144 \text{ in.}^2}{\text{ft}^2} \right| \frac{1 \text{ Btu}}{778 (\text{ft})(\text{lb}_f)}$$

$$= -26.7 \text{ Btu/lb}$$

$$\Delta U = [(-117) - (-26.7)] (0.37) = -33.41 \text{ Btu}$$

$$W = (-33.41) - (-40) = \boxed{6.6 \text{ Btu}}$$

5.71 Pick the room as the system. The simplified form of the energy balance is (for no mass flow):

$$\Delta E = Q + W + S = \Delta U$$

where $Q = 0$ (room is insulated)

(continued)

Solutions-Chapter-5

$$W = 0 \text{ (constant volume)}$$

S = electrical energy provided freezer through the system boundary and is positive.

Hence $\Delta E = C_v \Delta T$ is positive and ΔT is positive; i.e. the temperature increases.

5.72

Process: batch

System: water

Basis: 1 lb H_2O @ $70^\circ F$

$70^\circ F$

$\Delta \hat{H}$: 38.05 Btu

p^* : 0.3628 psia

$\hat{V}$: 0.01605 $\frac{ft^3}{lb_m}$

$80^\circ F$

48.02

0.5067

0.01607

a. $Q + W = \Delta U + \cancel{\Delta K} + \cancel{\Delta P}$ and $\Delta U = \Delta H - \Delta(pV)$

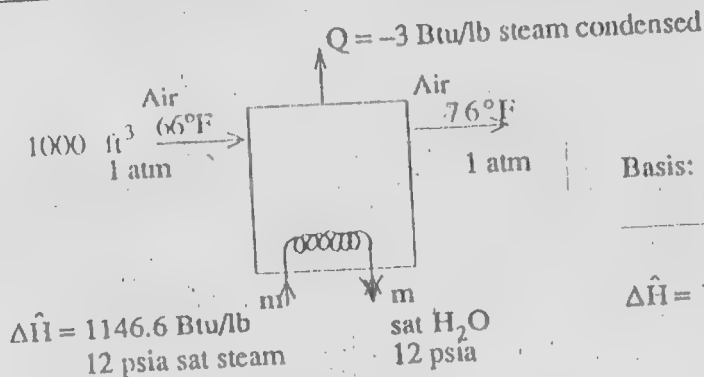
$$\hat{W} = 0; Q = \Delta U = C_v \Delta T \equiv C_p (80 - 70) = 10 \text{ Btu}$$

$$\Delta H = \Delta U - \Delta(pV) \equiv \Delta U = \Delta E$$

b. $\text{Assume } Q = 0; W = \Delta U \equiv \Delta H = C_p \Delta T = 10 \text{ Btu}$

W is positive (work done on system).

5.73



Basis: 1000 ft^3
at 1 atm and $66^\circ F$

$$\Delta \hat{H} = 170 \text{ Btu/lb}$$

$$\Delta \hat{H} = 1146.6 \text{ Btu/lb}$$

12 psia sat steam

$$m$$

sat H_2O
12 psia

$$-\Delta \hat{H} + Q + \cancel{W} = \cancel{\Delta E}$$

Steady state, no PE, no KE, no W

$$Q = \Delta H$$

$$Q = \frac{-3 \text{ Btu}}{\text{lb steam}} \left| \frac{m \text{ lb steam}}{1 \text{ lb steam}} \right| = -3m$$

(continued)

$$-3m = (170 - 1146.6) \frac{\text{Btu}}{\text{lb steam}} m + \left[\int_{T_{\text{ref}}}^{76} C_{p, \text{air}} dT - \int_{T_{\text{ref}}}^{66} C_{p, \text{air}} dT \right] n$$

$$\int_{66}^{76} (C_{p, \text{air}}) dT$$

$$\int_{66}^{76} 6.900 + 0.02884 \times 10^{-2} + 0.02429 \times 10^{-5} - 0.0852 \times 10^{-9} dT$$

$$= 6.900(76 - 66) + \frac{0.02884 \times 10^{-2}}{2} (76^2 - 66^2) + \frac{0.02429 \times 10^{-5}}{3} (76^3 - 66^3) - \frac{0.08052 \times 10^{-9}}{4} (76^4 - 66^4) = 69.03 \text{ Btu/lb mol}$$

$$n = \frac{pV}{RT} = \frac{1 \text{ atm} | 100 \text{ ft}^3}{0.7302 (\text{ft}^3)(\text{atm}) | 531^\circ \text{R}} = 2.58 \text{ lb mol}$$

$$\frac{(\text{lb mol})(^\circ \text{R})}{(\text{lb mol})(^\circ \text{R})}$$

$$973.6m = 69.03 (2.58) \quad m = 0.18 \text{ lb steam}$$

5.74 Assume steady state, no change in height or velocity, and $Q = 0$.

Basis: 1 hr

10 atm = 1013 kPa

$$\Delta E = -[(\Delta \hat{H} + \Delta \hat{K} + \Delta \hat{P})m] + Q + W$$

$$W = \Delta \hat{H}m = (\Delta \hat{H}_2 - \Delta \hat{H}_1)m$$

IC

FC

p: 1013 kPa ~ 1000 kPa

p: 101.3 kPa saturated

T: 500K

T = 373.1 K

$\Delta \hat{H}_1$: 2890.2 kJ/kg

$\Delta \hat{H}_2$: 2675.6 kJ/kg

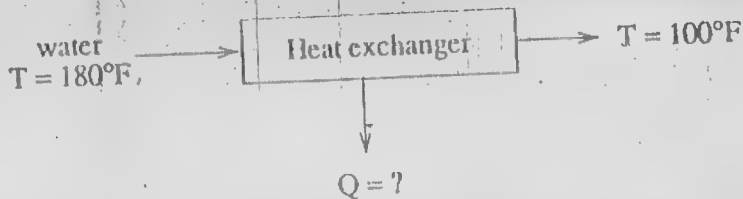
$$W = (2675.6 - 2890.2) (700) = -150,200 \text{ kJ/hr}$$

(work done by the system per hour)

$$= \frac{-150,200 \text{ kJ}}{\text{hr}} \left| \frac{(s)(1W)}{1J} \right| \frac{1 \text{ hr}}{3600s} = -41.7 \text{ kW}$$

(continued)

5.75



Assume: Steady state, no change in elevation (no potential energy), and constant velocity (no $\Delta \hat{K}$). No work is done on or by the system.

$$\Delta \hat{E} = -(\Delta \hat{H} \Delta \hat{K} + \Delta \hat{P})m + Q + \dot{W}$$

$$Q = \Delta \hat{H} m = (\Delta \hat{H}_2 - \Delta \hat{H}_1)m$$

From the steam tables

$$\Delta \hat{H}_1 = 148.00 \text{ Btu/lb}$$

$$\Delta \hat{H}_2 = 67.999 \text{ Btu/lb}$$

$$m = 62.4 \frac{\text{lb}_m}{\text{ft}^3} \left| \frac{100 \text{ ft}^3}{\text{hr}} \right| = 6240 \frac{\text{lb}_m}{\text{hr}}$$

$$Q = (67.999 - 148.00) \frac{\text{Btu}}{\text{lb}_m} \left| \frac{6240 \text{ lb}_m}{\text{hr}} \right| = -4.99 \times 10^5 \frac{\text{Btu}}{\text{hr}}$$

(heat removed)

5.76 (a) Assume steady state flow process. The system includes the orifice.

$$\Delta \hat{E} = Q + W - \Delta \hat{H} - \Delta \hat{P} - \Delta \hat{K}$$

$$\Delta \hat{E} = 0 \text{ (steady state)} \quad \Delta \hat{P} = 0$$

$$Q = 0 \text{ (adiabatic essentially)} \quad \Delta \hat{K} \approx 0$$

$$W = 0 \text{ (no work done)}$$

Final simplified equation: $\Delta \hat{H} = 0$

$$(b) \quad \Delta \hat{K} \approx 0, \quad Q = 0, \quad \Delta \hat{P} = 0, \quad \Delta \hat{E} = 0$$

$$\Delta \hat{H} = W$$

(continued)

$$(c) \quad \Delta P = 0, \Delta K = 0, \Delta E = 0, W = 0, Q = 0$$

$$\Delta H = 0$$

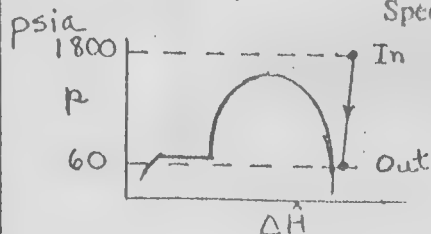


For adiabatic throttling: $\hat{H}_{in} = \hat{H}_{out}$ so we read on chart:

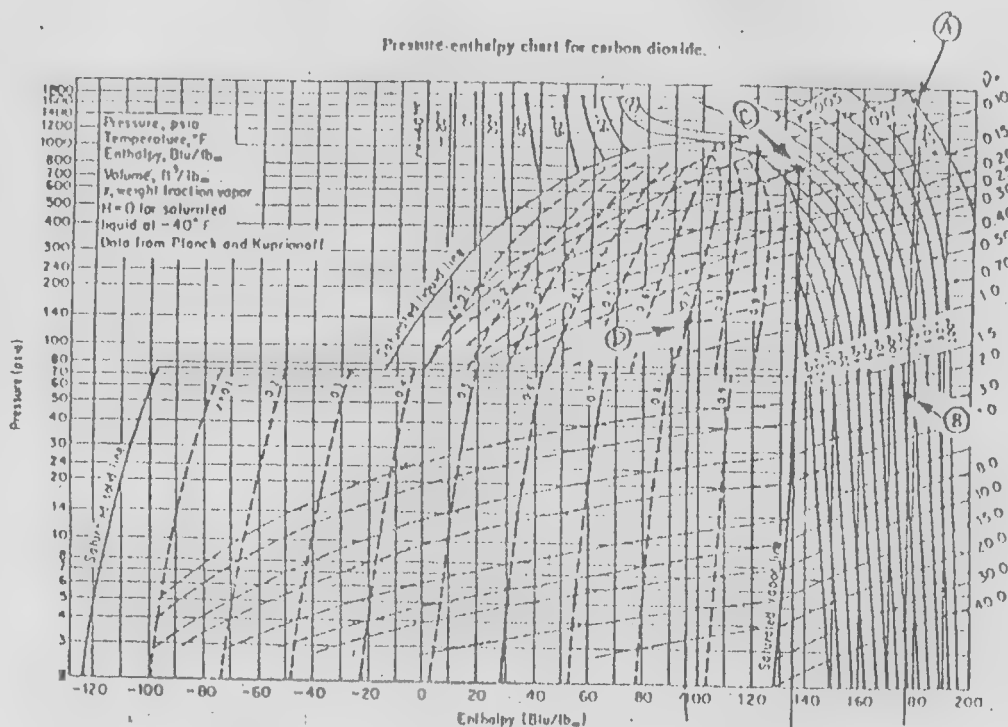
$$T \approx 130^\circ\text{F} \text{ (i)}$$

Superheated conditions so quality = 100% (ii)

Specific volume from chart = $2.5 \text{ ft}^3/\text{lb}$ (iii)



Pressure-enthalpy chart for carbon dioxide.



(continued)

5.78 Part 1

Assume the process is a steady state process. The system is the turbine.

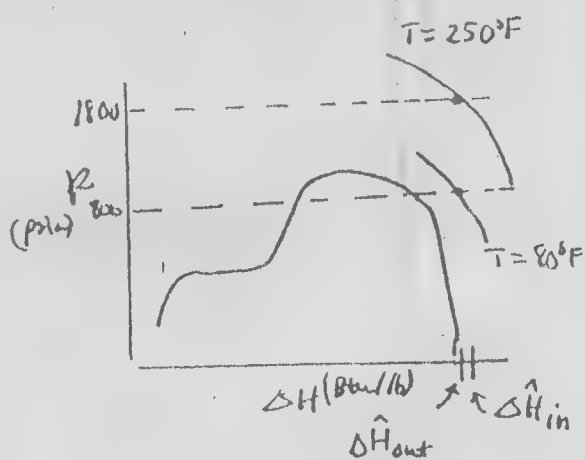
The energy balance is

$$\Delta E = Q + W - \Delta H - \Delta P - \Delta K$$

$$\Delta E = 0 \text{ (steady state)}$$

$$\Delta P = 0$$

$$\Delta K \approx 0 \text{ (quite small effect)}$$



(continued)

Solutions-Chapter-5

so that the energy balance reduces to $Q+W = \Delta H$

$$\Delta \hat{H}_{in} = 177 \text{ Btu/lb} \quad \Delta \hat{H}_{out} = 135 \text{ Btu/lb} \quad Q = 25 \text{ Btu/lb}$$

Basis: 1 lb steam

$$\dot{W} = -(-25) + (135 - 177) = \boxed{-17 \text{ Btu/lb}} \text{ (Work done by turbine)}$$

Part 2

The system is the valve. The energy balance is not needed because the CO_2 is saturated at 140 psia, hence this corresponds to 38°F .

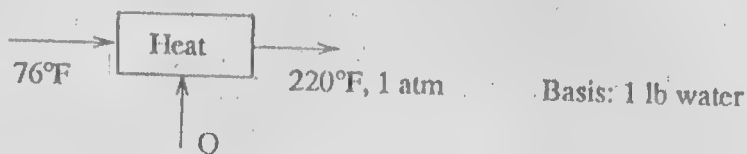
Part 3

The energy balance reduces to

$$\dot{Q} = \Delta \hat{H} = \Delta \hat{H}_{out} - \Delta \hat{H}_{in} = 95 - 135 = \boxed{-40 \text{ Btu/lb}} \text{ (heat removed)}$$

5.79

Assume a steady state process. The system is the heater.



$$\text{The energy balance reduces to: } Q = \Delta H = 1154.4 - 44.03 = \boxed{1110.4 \text{ Btu/lb}}$$

Alternate solution

Assume an unsteady state process with no mass exchanger between the system and surroundings.

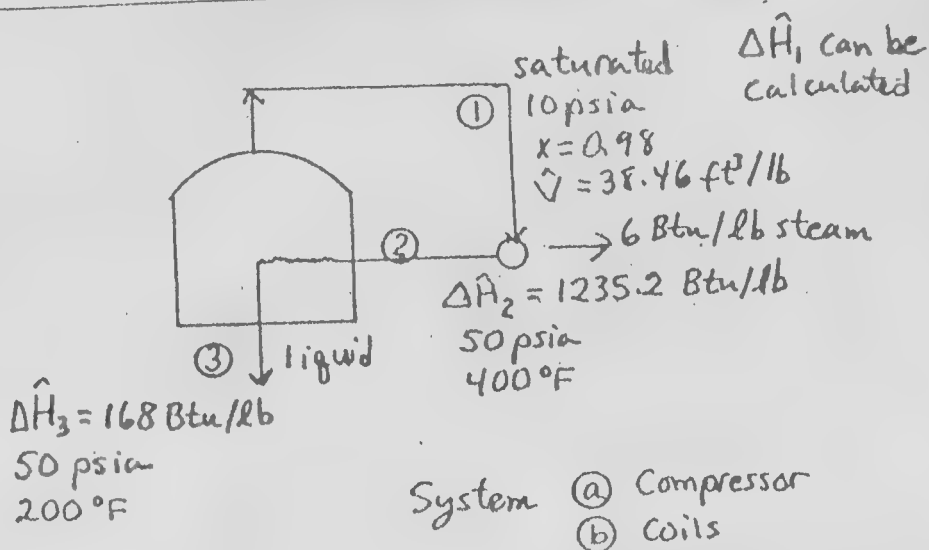
The energy balance reduces to

$$\Delta E = \Delta U = Q$$

$$\Delta U = \Delta H - \Delta(pV) = 1110.4 - \frac{14.7(27.17 - 0.01607) \text{ lb}_f}{\text{in}^2} \left| \frac{144 \text{ in}^2}{\text{ft}^2} \right.$$

$$\times \frac{\text{ft}^3}{\text{lb}_m} \left| \frac{1 \text{ Btu}}{778(\text{ft})(\text{lb}_f)} \right. = 1110.4 - 73.9 = \boxed{1036.5 \text{ Btu/lb}}$$

5.80



To make the process a steady state open process from ① to ③, assume the system is the coil plus the compressor. Then

$$\Delta \hat{E} = -\Delta[(\hat{H} + \hat{P} + \hat{K})m] + Q + W \quad \text{or} \quad W = \Delta H - Q$$

Basis: 1 lb water

Calculate $\Delta \hat{H}$ (a) ①: $(0.98)(1143.3) + (0.02)(161.17) = 1133.6 \text{ Btu/lb}$

From ① to ②:

$$\Delta \hat{H}_2 - \Delta \hat{H}_1 = 1235.2 - 1136.6 = 101.6 \text{ Btu/lb} \quad \hat{Q} = -6 \text{ Btu/lb}$$

$$W = 101.6 - (-6) = 107.6 \text{ Btu/lb}$$

From ② to ③:

$$\Delta \hat{H}_3 - \Delta \hat{H}_2 = 168 - 1235.2 = -1067.2 \text{ Btu/lb} \quad \hat{W} = 0 \text{ so } \hat{Q} = \Delta \hat{H}$$

a. $\frac{\hat{Q}}{\hat{W}} = \frac{1067.2}{107.6} = \boxed{9.9}$

$$\hat{V} = \left[\frac{38.46 \text{ ft}^3}{\text{lb}} \right] \frac{0.98}{1} + \left[\frac{(0.016) \text{ ft}^3}{\text{lb}} \right] \frac{0.02}{1} \left] \frac{\text{lb steam}}{1067.2 \text{ Btu}} \right.$$

b. $\frac{10^6}{\text{hr}} \frac{1 \text{ hr}}{60 \text{ min}} = \boxed{600 \text{ ft}^3/\text{min}}$

Solutions-Chapter-5

5.81

Basis: 55 gallon oil, °API = 15

$$C_p = 0.41 \frac{\text{Btu}}{(\text{lb}) (^\circ\text{F})} @ 70^\circ\text{F}; \quad C_p = 0.467 \frac{\text{Btu}}{(\text{lb}) (^\circ\text{F})} @ 180^\circ\text{F}$$

$$C_{p_{\text{mix}}} = 0.5 (0.41 + 0.467) = 0.44 \text{ Btu}/(\text{lb}) (^\circ\text{F})$$

$$\text{sp. gr.} = \frac{141.5}{^\circ\text{API} + 131.5} = 0.966$$

$$\Delta H_{\text{oil}} = (0.44) (180 - 70) (55) (0.966) (8.33) = 21,500 \text{ Btu}$$

Assume water leaves @ 212°F, saturated liquid:

$$\Delta \hat{H}_{\text{H}_2\text{O}} @ 212^\circ\text{F} = 180.07 \text{ Btu/lb}$$

$$\Delta \hat{H}_{\text{H}_2\text{O}} @ 220^\circ\text{F} = 1153.3 \text{ Btu/lb}$$

$$\text{Then } \Delta \hat{H}_{\text{H}_2\text{O}} = 1153.3 - 180 = 973 \text{ Btu/lb}$$

$$m_{\text{steam}} = \frac{21,500 \text{ Btu}}{973 \text{ Btu}} \left| \frac{1 \text{ lb}}{1} \right| = \boxed{22.1 \text{ lb steam}}$$

5.82

Process: batch, steady state, no generation

System: the pipeline

$$\text{a. } Q + W = \Delta H + \Delta K + \Delta P$$

Assume $\Delta \hat{K} = 0$

Basis: 1 lb_m of oil

$$\hat{Q} = \frac{1 \times 10^5 \text{ Btu}}{\text{hr}} \left| \frac{1 \text{ hr}}{60 \text{ min}} \right| \left| \frac{\text{min}}{2000 \text{ lb}} \right| = 0.834 \text{ Btu/lb}_m$$

$$\Delta \hat{P} = - \frac{1000 \text{ ft}}{1} \left| \frac{\text{g ft}}{\text{s}^2} \right| \left| \frac{(\text{lb}_p) (\text{s}^2)}{\text{g}_c (\text{lb}_m) (\text{ft})} \right| \left| \frac{1 \text{ Btu}}{778 (\text{ft}) (\text{lb}_p)} \right| = -1.285 \frac{\text{Btu}}{\text{lb}}$$

$$\text{Without the pump: } \Delta \hat{H} = 0.834 - (-1.285) = \boxed{2.120 \text{ Btu/lb}}$$

$$\text{b. } W = \frac{1 \text{ hp}}{1} \left| \frac{0.50}{1} \right| \left| \frac{550 (\text{ft}) (\text{lb}_p)}{(\text{sec}) (\text{hp})} \right| \left| \frac{60 \text{ sec}}{\text{min}} \right| \left| \frac{1 \text{ Btu}}{778 (\text{ft}) (\text{lb}_p)} \right| \left| \frac{\text{min}}{2000 \text{ lb}_m} \right| = 0.0106 \text{ Btu/lb}$$

$$\text{With the pump: } \Delta H = 0.834 - (-1.285) + (0.0106) = \boxed{2.131 \text{ Btu/lb}}$$

5.83 a. $(E_2 - E_1) = -\Delta[(\hat{H} + \hat{K} + \hat{P})_m] + Q + W$ for all parts of this problem

1. Ignore $\hat{P}$; $\Delta\hat{P} = 0$
2. $\Delta\hat{K}$ is small so $\Delta\hat{K} = 0$ (or it can be included)
3. No reaction
4. $W = 0$
5. $(E_2 - E_1) = 0$; steady state

$$\Delta H = Q$$

- b. 1. Ignore $\hat{P}$; $\Delta\hat{P} = 0$
2. No reaction
 3. $W = 0$
 4. $(E_2 - E_1) = 0$; steady state
 5. $Q = 0$

$$-\Delta[(\hat{H} + \hat{K})_m] = 0$$

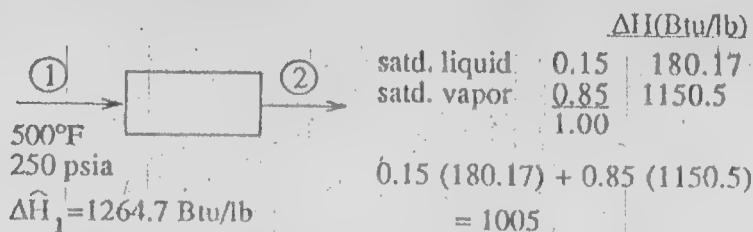
- c. 1. Ignore $\hat{P}$; $\Delta\hat{P} = 0$
2. $\Delta\hat{K} = 0$
 3. No reaction
 4. $(E_2 - E_1) = 0$; steady state
 5. $Q = 0$ (assume)

$$\Delta H = W$$

- d. 1. Ignore $\hat{P}$; $\Delta\hat{P} = 0$
2. No reaction
 3. $(E_2 - E_1) = 0$; steady state (may be not the $\Delta\hat{K}$)
 4. $Q = 0$ (assumed)

$$\Delta[(\hat{H} + \hat{K})_m] = W$$

5.84



Basis: 1 hour

Assume a steady state flow system ($\Delta F = 0$) and $\Delta P = \Delta K = 0$

$$\Delta H = Q + W$$

$$\Delta H = m(\Delta \hat{H}_2 - \Delta \hat{H}_1) = 1000 (1005 - 1264.7) = -259,700 \text{ Btu}$$

$$W = \frac{-86.5 \text{ hp} \left| \frac{33,500 \text{ (ft) (lb}_p\text{)}}{(\text{hp}) (\text{min})} \right| \frac{1 \text{ Btu}}{778 \text{ (ft) (lb}_p\text{)}} \left| \frac{60 \text{ min}}{\text{hr}} \right|}{\text{hr}} = -223,500 \text{ Btu/hour}$$

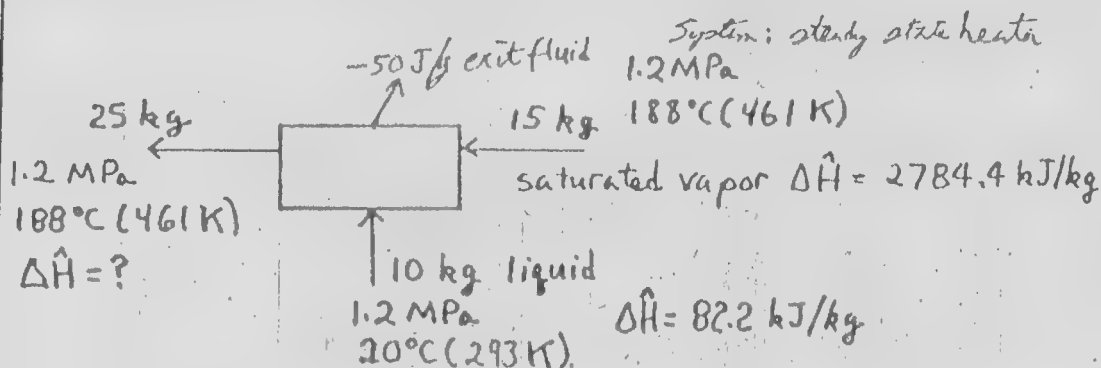
$$Q = \Delta H - W = -259,700 - (-223,500)$$

$$= \boxed{-36,200 \text{ Btu/hr}} \quad (\text{heat loss})$$

The turbine does not operate adiabatically.

5.85

Basis: 1 second



$$Q + \cancel{W} = \Delta H = \Delta H_{25} - \Delta H_{15} - \Delta H_{10} = \Delta H_{25} - (2784.4)(15) - (82.2)(10)$$

$$Q = \frac{-50 \text{ J}}{\text{g, exit}} \left| \frac{25 \times 10^3 \text{ g}}{\text{g, exit}} \right| = -1250 \text{ kJ} \quad (\text{note } \Delta \hat{K} \sim 10^{-4} \text{ J})$$

(continued)

Solutions-Chapter-5

For the exit fluid. $\begin{cases} \Delta \hat{H}_L = 798.5 \text{ kJ/kg} \\ \Delta \hat{H}_V = 2784.4 \text{ kJ/kg} \end{cases}$

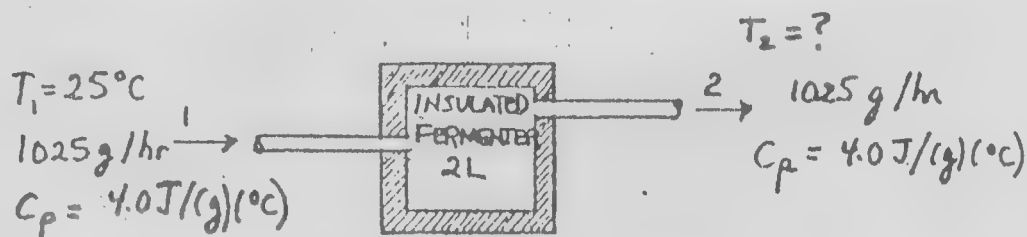
Let $x = \text{kg vapor}$, $1 - x = \text{kg liquid}$

$$1250 = \frac{x \text{ kg}}{\text{kg}} | 2784.4 \text{ kJ} + \frac{(1-x) \text{ kg}}{\text{kg}} | 798.5 \text{ kJ} - \frac{15 \text{ kg}}{\text{kg}} | 2784.4 \text{ kJ} - \frac{10 \text{ kg}}{\text{kg}} | 82.2 \text{ kJ}$$

$$-1250 = 2784.4x + 798.5 - 798.5x - 41,766 - 822$$

$$x = 21.67 \quad \text{fraction vapor} = \frac{21.7}{25.0} = \boxed{0.87}$$

5.86



$$\Delta H_{rxn} = 27.6 \text{ kJ/(L)(hr)}$$

Open steady state system: the inside of the cell.

Basis: 1 hr

$$\Delta H + Q + W \quad Q = 0 \quad W = 0$$

$$\Delta H = 0$$

$$\Delta H_{sfr} + \Delta H_{rxn} = 0$$

$$m_2 C_{p2} (T_2 - T_{ref}) - m_1 C_{p1} (T_1 - T_{ref}) + \Delta H_{rxn} = 0$$

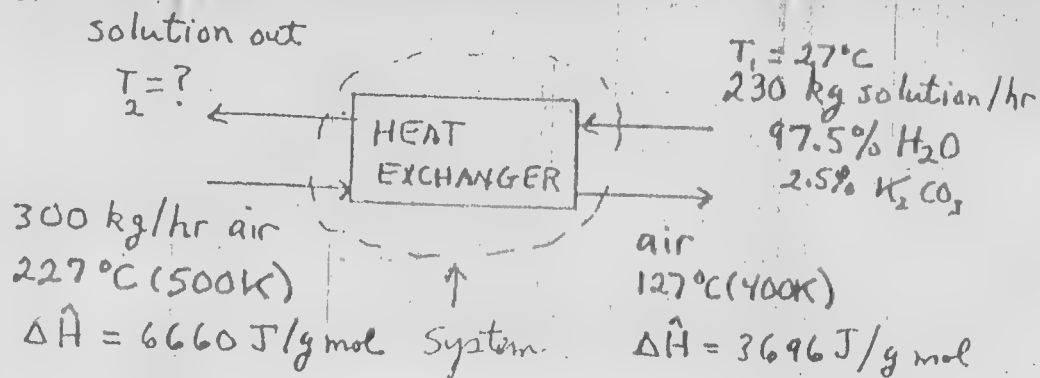
Let $T_{ref} = 25^\circ\text{C}$

$$\frac{1 \text{ hr}}{\text{hr}} | \frac{1025 \text{ g}}{\text{hr}} | \frac{4.0 \text{ J}}{(\text{g})(^\circ\text{C})} | T_2 - 25^\circ\text{C} - \frac{1 \text{ hr}}{\text{hr}} | \frac{1025 \text{ g}}{\text{hr}} | \frac{4.0 \text{ J}}{(\text{g})(^\circ\text{C})} | (25 - 25)^\circ\text{C}$$

$$+ \frac{1 \text{ hr}}{\text{hr}} | \frac{27.6 \text{ kJ}}{(\text{L})(\text{hr})} | \frac{2 \text{ L}}{\text{L}} | \frac{1000 \text{ J}}{\text{kJ}} = 0$$

$$T_2 = \frac{(55,200 + 102,500) \text{ J}}{4,100 \text{ J/}^\circ\text{C}} = \boxed{38^\circ\text{C, yes}}$$

5.87



Basis: 1 hr

The energy balance reduces to

$$\Delta H = 0$$

$$\Delta H_{\text{air}} + \Delta H_{\text{soln}} = 0$$

For aqueous solutions, the heat capacity is dominated by the water, and the solute mass may be neglected with minimal error.

$$m \left(\Delta H_{\text{air}}^{400} - \Delta H_{\text{air}}^{500} \right) + m \left(\Delta H_{\text{H}_2\text{O}}^{T_2} - \Delta H_{\text{H}_2\text{O}}^{300} \right) = 0$$

$$\frac{1 \text{ hr}}{\text{hr}} \left| \frac{300 \text{ kg}}{\text{hr}} \right| \left| \frac{(3696 - 6660) \text{ J}}{\text{g mol}} \right| \left| \frac{\text{g mol}}{29 \text{ g}} \right| \left| \frac{1000 \text{ g}}{\text{kg}} \right| \left| \frac{\text{kJ}}{1000 \text{ J}} \right|$$

$$+ \frac{1 \text{ hr}}{\text{hr}} \left| \frac{230 \text{ kg soln}}{\text{hr}} \right| \left| \frac{97.5 \text{ kg H}_2\text{O}}{100 \text{ kg soln}} \right| \left| \frac{(\Delta H_{\text{H}_2\text{O}}^{T_2} - 111.7) \text{ kJ}}{\text{kg}} \right| = 0$$

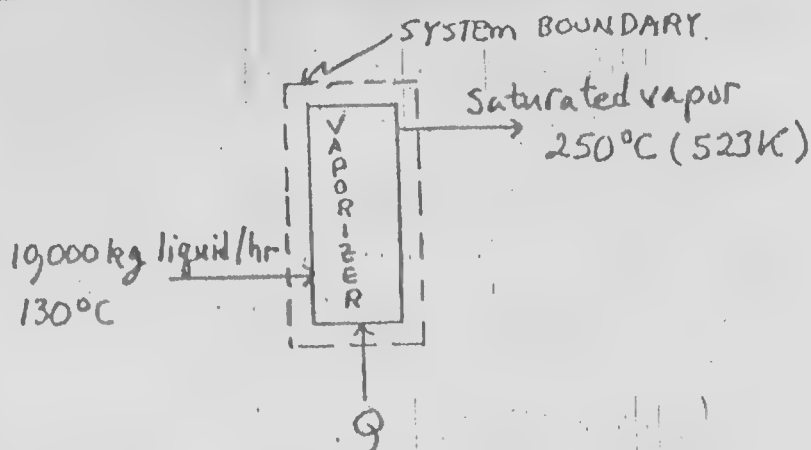
$$\Delta H_{\text{H}_2\text{O}}^{T_2} = \frac{(30,622 + 25,049) \text{ kJ}}{224.25 \text{ kg}} = \boxed{248 \frac{\text{kJ}}{\text{kg}}}$$

Interpolating from SI steam tables

$$330 \text{ K} + \frac{(335 - 330) \text{ K}}{(259.4 - 238.4) \frac{\text{kJ}}{\text{kg}}} (248.25 - 238.4) \frac{\text{kJ}}{\text{kg}}$$

$$= \boxed{332 \text{ K or } 59^\circ\text{C}}$$

5.88



Basis: 1 hr

Open system, steady state

$$\Delta H = Q + W$$

$$W = 0$$

$$Q = \Delta H_{\text{liq}} + \Delta H_{\text{vap}} \text{ at } 6 \text{ bp.}$$

$$= m \left[\int_{130}^{250} C_p dT + \Delta H_{\text{vap}} \text{ at } 250^\circ\text{C} \right]$$

Since the data are incomplete the following assumptions are made:

1. C_p is linear in T and the average value may be used.
2. The vapor behaves ideally.
3. V_L is negligible with respect to V_v .
4. $\Delta \hat{H}_{\text{vap}}$ is constant within the temperature range of concern.

$$\text{By 1, } C_{pL} = \frac{(2.09 + 2.13) \text{ J/(g)} (^\circ\text{C})}{2} = 2.11 \text{ J/(g)} (^\circ\text{C})$$

By 2, 3, 4 the Clausius Clapeyron equation reduces to

$$\log_{10} \frac{p^*_1}{p^*_2} = \frac{\Delta \hat{H}_{\text{vap}}}{2.303 R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

(continued)

Solutions-Chapter-5

Substituting values:

$$\log_{10} \left(\frac{55.0 \text{ kPa}}{101.3 \text{ kPa}} \right) = \frac{\Delta \hat{H}_{\text{vap}}}{2.303} \left(\frac{\text{g mol}}{8.314 \text{ J}} \right) \left(\frac{1}{523 \text{ K}} - \frac{1}{503 \text{ K}} \right)$$

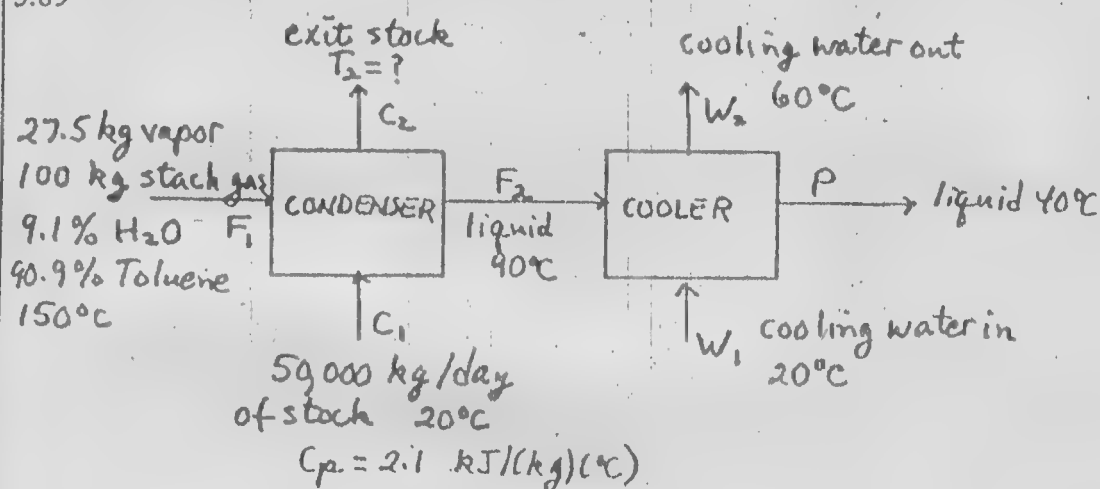
$$-0.2654 = -3.97060 \times 10^{-6} \Delta \hat{H}_{\text{vap}} \frac{\text{g mol}}{\text{J}}$$

$$\Delta \hat{H}_{\text{vap}} = \frac{-0.2654 \text{ J}}{-3.9706 \times 10^{-6} \text{ g mol}} \left(\frac{1 \text{ g mol}}{122 \text{ g}} \right) = 547.88 \text{ kJ/kg}$$

$$Q = \frac{1 \text{ hr}}{1 \text{ hr}} \left| \frac{10,000 \text{ kg}}{\text{hr}} \left[\frac{2.11 \text{ kJ}}{(\text{kg})(^{\circ}\text{C})} (250 - 130)^{\circ}\text{C} + \frac{547.88 \text{ kJ}}{\text{kg}} \right] \right|$$

$$= 8,011,000 \text{ kJ}$$

5.89



Basis: 1 day

$$\frac{27.5 \text{ kg } F_1}{100.0 \text{ kg stock}} \left| \frac{50,000 \text{ kg}}{\text{day}} \right| \frac{1 \text{ day}}{1} = 13,750 \text{ kg } F_1$$

$$\frac{13,750 \text{ kg } F_1}{1} \left| \frac{9.1 \text{ kg H}_2\text{O}}{\text{kg } F_1} \right| = 1,251.25 \text{ kg H}_2\text{O}$$

$$13,750 \text{ kg } F_1 - 1,251.25 \text{ kg H}_2\text{O} = 12,498.75 \text{ kg toluene.}$$

(continued)

Energy balance at condenser:

The energy balance reduces to $\Delta H = 0$

$$\Delta H_{\text{stock}} + \Delta H_{\text{feed}} = 0$$

$$(\Delta H_{C_2} - \Delta H_{C_1}) + (\Delta H_{F_2} - \Delta H_{F_1}) = 0$$

$$m_C \int_{20}^{T_2} C_p dT + m_{H_2O} \left[\int_{150}^{100} C_p dT - \Delta H_{\text{vap at } 100^\circ\text{C}} + \int_{100}^{90} C_p dT \right]$$

$$+ m_{\text{tol}} \left[\int_{150}^{111} C_p dT - \Delta H_{\text{vap at } 111^\circ\text{C}} + \int_{111}^{90} C_p dT \right] = 0$$

$$\frac{50,000 \text{ kg}}{(\text{kg})} \left| \frac{2.1 \text{ kJ}}{(\text{kg}) (^\circ\text{C})} \right| \frac{T_2 - 20^\circ\text{C}}{454 \text{ g}}$$

$$+ 1,251.25 \text{ kg } H_2O \left[\frac{2.1 \text{ kJ}}{(\text{kg}) (^\circ\text{C})} \right] \frac{(100 - 150)^\circ\text{C}}{1} - \frac{2260 \text{ kJ}}{\text{kg}} + \frac{4.2 \text{ kJ}}{(\text{kg}) (^\circ\text{C})} \left| \frac{(90 - 100)^\circ\text{C}}{1} \right|$$

$$+ 12,498.75 \text{ kg tol} \left[\frac{1.3 \text{ kJ}}{(\text{kg})(^\circ\text{C})} \right] \frac{(111 - 150)^\circ\text{C}}{1} - \frac{230 \text{ kJ}}{\text{kg}} + \frac{1.7 \text{ kJ}}{(\text{kg}) (^\circ\text{C})} \left| \frac{(90 - 111)^\circ\text{C}}{1} \right| = 0$$

$$105,000 T_2 - 2,100,000 - 3,011,758.75 - 3,954,604.5 = 0$$

$$T_2 = \frac{9,066,363.25}{105,000} = \boxed{86.3^\circ\text{C}}$$

Enthalpy balance at cooler:

$$\Delta H = 0$$

$$(\Delta H_{W_2} - \Delta H_{W_1}) - (\Delta H_P - \Delta H_F) = 0$$

$$m_W \int_{20}^{60} C_p dT - \left[m_{H_2O} \int_{86.34}^{40} C_p dT - m_{\text{td}} \int_{86.34}^{40} C_p dT \right] = 0$$

(continued)

Solutions-Chapter-5

$$\frac{m_w}{(\text{kg})(^\circ\text{C})} \left| \frac{4.2 \text{ kJ}}{(60 - 20)^\circ\text{C}} \right| = \frac{1,251.25 \text{ kg H}_2\text{O}}{(\text{kg})(^\circ\text{C})} \left| \frac{4.2 \text{ kJ}}{(40 - 90)^\circ\text{C}} \right|$$

$$+ \frac{12498.75 \text{ kg tol}}{(\text{kg})(^\circ\text{C})} \left| \frac{1.7 \text{ kJ}}{(40 - 90)^\circ\text{C}} \right|$$

$$m_w = 168 \frac{\text{kJ}}{\text{kg}} - 262,762 \text{ kJ} - 1,062,394 \text{ kJ}$$

$$m_w = \frac{1,325,156 \text{ kJ}}{168 \text{ kJ/kg}} = 7,887 \text{ kg H}_2\text{O}$$

5.90

General balance is

$$\Delta E = \Delta U + \Delta K + \Delta P = -\Delta[(\hat{H} + \hat{K} + \hat{P})m] + Q + W$$

① ② ③
④ ⑤ ⑥
⑦ ⑧

Assume all reactants are in bomb at start of reaction.

a.

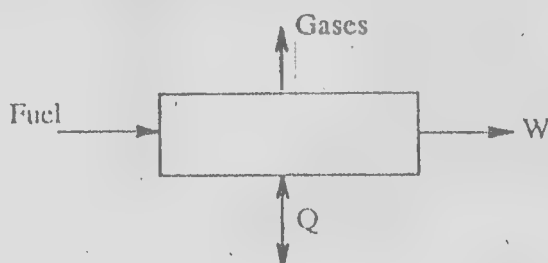


- | | | | |
|---|--------------|----------------------------------|--------------|
| 1 | ΔU | retain because changes | |
| 2 | ΔK | delete - no change | |
| 3 | ΔP | delete - no change | |
| 4 | } ΔH | delete as no mass flow in or out | |
| 5 | | | } ΔK |
| 6 | | | |
| 7 | Q | retain | |
| 8 | W | delete - no work done | |

$$\Delta U = Q \text{ is final relation}$$

(continued)

b.



$$\Delta H = Q - W$$

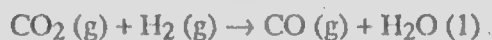
- | | | | |
|----|---------------------------------------|---|--------------------------|
| 1) | | 5 | delete as negligible |
| 2) | } $\Delta E = 0$ because steady state | 6 | delete not a factor |
| 3) | | 7 | Q keep |
| 4 | ΔH keep | 8 | W keep (electric work) |

c.

- | | | | |
|----|-------------------------------|---|----------------------------------|
| 1) | | 5 | ΔK delete negligible |
| 2) | } $\Delta U = 0$ steady state | 6 | ΔP delete not applicable |
| 3) | | 7 | $Q = 0$ insulated applicable |
| 4 | ΔH is kept | 8 | $W = 0$ no work done |

$$\Delta H = 0$$

5.91

a. Basis: 1 g mol CO_2 (g)

$$\Delta H^\circ_{\text{rxn}} = (-110.52 - 285.84) - (-393.51) = \boxed{-2.849 \text{ kJ}}$$

b. Basis: 1 g mol CaO (s)

$$\Delta H^\circ_{\text{rxn}} = (-986.59 - 924.66) = [(-635.55 - 601.83) - 2(285.84)] = \boxed{-102.19 \text{ kJ}}$$

c. Basis: 1 g mol Na_2SO_4 (s)

$$\Delta H^\circ_{\text{rxn}} = (-1090.35 - 110.54) - (-1384.49) = \boxed{183.59 \text{ kJ}}$$

(continued)

Solutions-Chapter-5

d. Basis: 1 g mol NaCl (s)

$$\Delta H^\circ_{\text{rxn}} = (-92.31 - 1126.33) - (-811.32 - 411.01) = \boxed{3.67 \text{ kJ}}$$

e. Basis: 1 g mol O₂

$$\Delta H^\circ_{\text{rxn}} = [2 (-1216.96) + 4 (-92.31)] - [4 (-411.00) + 2 (-296.90) + 2 (-285.84)] = \boxed{-328.78 \text{ kJ}}$$

f. Basis: 1 g mol SO₂ (g)

$$\Delta H^\circ_{\text{rxn}} = (-811.32) - (-285.84 - 296.90) = \boxed{-228.58 \text{ kJ}}$$

g. Basis: 1 g mol N₂

$$\Delta H^\circ_{\text{rxn}} = 2 (90.374) = \boxed{180.75 \text{ kJ}}$$

h. Basis: 1 g mol Na₂CO₃ (s)

$$\Delta H^\circ_{\text{rxn}} = [3 (-1117.13) + (-412.96)] - [-1130.94 + 2 (-373.21) + 4 (-296.90)] = \boxed{-699.56 \text{ kJ}}$$

i. Basis: 1 g mol CS₂ (l)

$$\Delta H^\circ_{\text{rxn}} = (-1394.69 - 60.25) - (+87.86) = \boxed{-287.61 \text{ kJ}}$$

j. Basis: 1 g mol C₂H₂ (g)

$$\Delta H^\circ_{\text{rxn}} = (+105.02) - (52.28 - 92.31) = \boxed{-145.05 \text{ kJ}}$$

k. Basis: 1 g mol CH₃OH (g)

$$\Delta H^\circ_{\text{rxn}} = (-115.90 - 241.82) - (-201.25) = \boxed{-156.48 \text{ kJ}}$$

l. Basis: 1 g mol C₂H₂ (g)

$$\Delta H^\circ_{\text{rxn}} = (-116.36) - (226.75 - 285.84) = \boxed{107.24 \text{ kJ}}$$

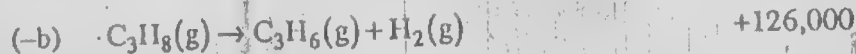
m. Basis: 1 g mol C₄H₁₀ (g)

$$\Delta H^\circ_{\text{rxn}} = (52.28 - 84.67) - (-124.73) = \boxed{92.34 \text{ kJ}}$$

Solutions-Chapter-5

5.92

$\Delta H_{\text{Rxn}} (\text{J})$



Total -61,616

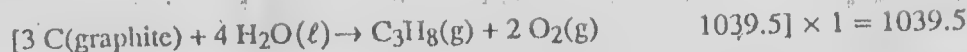
5.93

1 g mol propylene

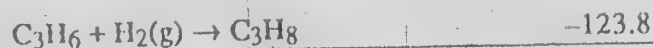
$\Delta H^\circ (\text{kJ})$



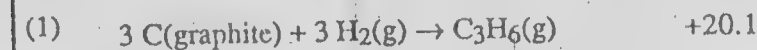
Subtract



Add

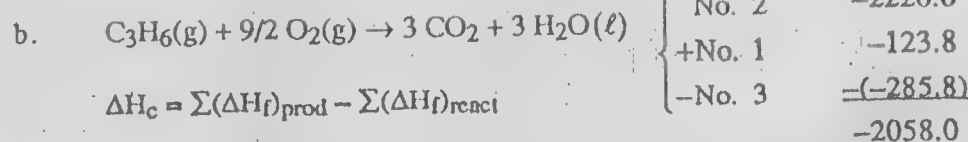


Subtract



a. $\Delta H^\circ_f \text{ of } \text{C}_3\text{H}_6 = \boxed{20.1 \text{ kJ/gmol}}$

Basis: 1 g mol C_3H_6



$\Delta H_c = \sum(\Delta H_f)_{\text{prod}} - \sum(\Delta H_f)_{\text{reac}}$

$\Delta H_c = 3(-393.5) + 3(-285.8) - (20.1 + 0) = \boxed{-2058.0 \text{ kJ/gmol}}$

Solutions-Chapter-5

5.94 The $\Delta \hat{H}_f^\circ$ is 0 by definition.

5.95 $\Delta \hat{H}_f^\circ$ of Fe_2O_3 is calculated as follows.

$$(1) \quad \Delta H_{\text{Rxn}} = \sum n_i \Delta \hat{H}_{f_i}^\circ - \sum n_i \Delta \hat{H}_{f_i}^\circ$$

products reactants

$$-822.200 \text{ kJ} = \Delta \hat{H}_{f_{\text{Fe}_2\text{O}_3}}^\circ - \Delta \hat{H}_{f_{\text{Fe}}}^\circ (2) - \Delta \hat{H}_{f_{\text{O}_2}}^\circ \left(\frac{3}{2}\right)$$

$$= \Delta \hat{H}_{f_{\text{Fe}_2\text{O}_3}}^\circ - 0 - 0$$

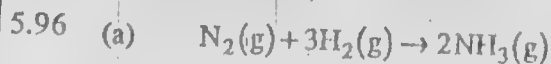
$$(2) \quad \Delta H_{\text{Rxn}} = -284.100 \text{ kJ}$$

$$= \Delta \hat{H}_{f_{\text{Fe}_2\text{O}_3}}^\circ - \Delta \hat{H}_{f_{\text{Fe}}}^\circ (2) - \Delta \hat{H}_{f_{\text{O}_2}}^\circ \left(\frac{1}{2}\right)$$

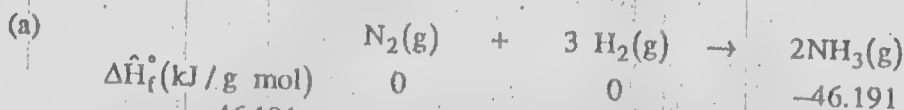
$$-284.100 = -822.200 - \Delta \hat{H}_{f_{\text{Fe}}}^\circ (2) - 0\left(\frac{1}{2}\right)$$

$$\Delta \hat{H}_{f_{\text{Fe}}}^\circ = \frac{-538.10}{2} \text{ kJ} = \boxed{-269.05 \text{ kJ}}$$

vs -267 in Appendix F

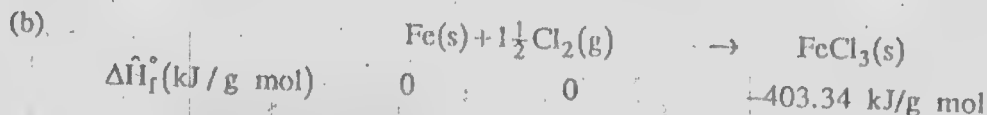


Basis: 1 g mol $\text{NH}_3(\text{g})$



$$\Delta \hat{H}_f^\circ = -\frac{46.191}{2} \text{ kJ/g mol NH}_3 = \boxed{-23.096 \text{ kJ/g mol NH}_3}$$

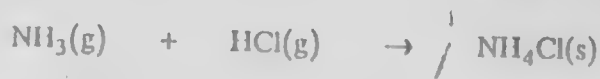
Basis: 1 g mol $\text{FeCl}_3(\text{s})$



$$\Delta \hat{H}_f^\circ = \boxed{-403.34 \text{ kJ/g mol FeCl}_3}$$

Solutions-Chapter-5

5.97 a. Basis: 1 g mol $\text{NH}_3(\text{g})$



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -46.191 \quad -92.311 \quad -315.4$$

$$\begin{aligned} \Delta H_{\text{rxn}}^\circ &= \sum_{\text{products}} n_i \Delta \hat{H}_i^\circ - \sum_{\text{reactants}} n_i \Delta \hat{H}_i^\circ \\ &= (1)(-315.4) - [(1)(-46.191) + (1)(-92.311)] \\ &= \boxed{-176.9 \text{ kJ/g mol NH}_3(\text{g})} \end{aligned}$$

b. Basis: 1 g mol $\text{CH}_4(\text{g})$



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -74.84 \quad 0 \quad -393.51 \quad -285.840$$

$$\begin{aligned} \Delta H_{\text{rxn}}^\circ &= \sum_{\text{products}} n_i \Delta \hat{H}_i^\circ - \sum_{\text{reactants}} n_i \Delta \hat{H}_i^\circ \\ &= [(1)(-285.840) + (1)(-393.51)] - [(1)(-74.84) + 0] \\ &= -604.51 \text{ kJ/g mol CH}_4(\text{g}) \end{aligned}$$

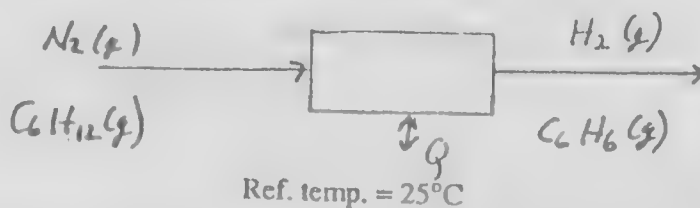
c. Basis: 1 g mol $\text{C}_6\text{H}_{12}(\text{g})$



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -123.1 \quad +48.66 \quad 0$$

$$\Delta H_{\text{rxn}}^\circ = [0 + (1)(+48.66)] - [(1)(-123.1)] = \boxed{171.76 \text{ kJ/g mol C}_6\text{H}_{12}(\text{g})}$$

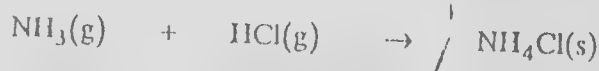
5.98 Assume steady state flow process with reaction.



(continued)

Solutions-Chapter-5

5.97 a. Basis: 1 g mol $\text{NH}_3(\text{g})$



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -46.191 \quad -92.311 \quad -315.4$$

$$\Delta H_{\text{rxn}}^\circ = \sum_{\text{products}} n_i \Delta \hat{H}_i - \sum_{\text{reactants}} n_i \Delta \hat{H}_i$$

$$= (1)(-315.4) - [(1)(-46.191) + (1)(-92.311)]$$

$$= \boxed{-176.9 \text{ kJ/g mol NH}_3(\text{g})}$$

b. Basis: 1 g mol $\text{CH}_4(\text{g})$



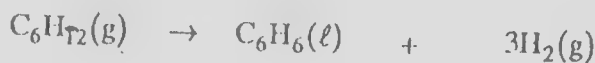
$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -74.84 \quad 0 \quad -393.51 \quad -285.840$$

$$\Delta H_{\text{rxn}}^\circ = \sum_{\text{products}} n_i \Delta \hat{H}_i - \sum_{\text{reactants}} n_i \Delta \hat{H}_i$$

$$= [(1)(-285.840) + (1)(-393.51)] - [(1)(-74.84) + 0]$$

$$= -604.51 \text{ kJ/g mol CH}_4(\text{g})$$

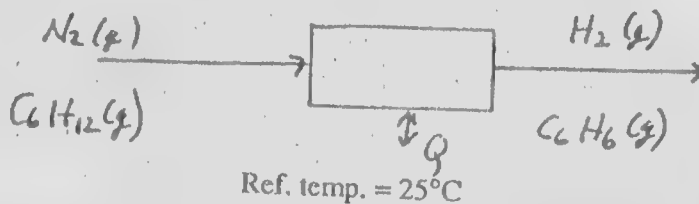
c. Basis: 1 g mol $\text{C}_6\text{H}_{12}(\text{g})$



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad -123.1 \quad +48.66 \quad 0$$

$$\Delta H_{\text{rxn}}^\circ = [0 + (1)(+48.66)] - [(1)(-123.1)] = \boxed{171.76 \text{ kJ/g mol C}_6\text{H}_{12}(\text{g})}$$

5.98 Assume steady state flow process with reaction.



(continued)

Solutions-Chapter-5

The standard heat of reactions is

$$\Delta \hat{H}_{Rxn}^{\circ} = [1(82,927) + 3(0)] - [1(-123,100)] = 2.06 \times 10^5 \text{ J/g mol } C_6H_{12}$$

Material balance:

Step 5: Basis: 1 g mol $C_6H_{12}(g)$ in

Steps 6 to 9: Make compound balances for each compound so that unknowns H_2 and C_6H_6 can be calculated.

$$\begin{aligned} \text{Results: } n_{H_2} \text{ out} &= 0.70(1)(3) = 2.10 & n_{C_6H_{12}} \text{ in} &= 1.0 \\ n_{C_6H_6} \text{ out} &= 0.70(1)(1) = 0.70 & n_{N_2} \text{ in} &= 0.50 \\ n_{C_6H_{12}} \text{ out} &= 0.30(1) = 0.30 \\ n_{N_2} \text{ out} &= 0.50 \end{aligned}$$

Energy balance

	Component	$\Delta \hat{H}_f^{\circ} (\text{J/gmol})$	$\int_{25}^T C_p dT^{\circ}$ (or use tables); $T=300^{\circ}\text{C}$	n_i	$\Delta \hat{H}_{25}^{300}$
Out:	$H_2(g)$	0	8056	0	2.10
	$C_6H_6(g)$	$+82.927 \times 10^3$	41,883	0	0.70
	$C_6H_{12}(g)$	-123.1×10^3	59,483	0	0.30
	$N_2(g)$	0	9213	0	0.50
In:	$C_6H_{12}(g)$	-123.1×10^3	0	0	1.00
	$N_2(g)$	0	0	0	0.50

$$(a) \quad Q = 1.44 \times 10^5 \text{ J/gmol} \quad (b) \quad Q = +2.129 \times 10^5 \text{ J/gmol}$$

*at 25°C exit temp. and entrance temp. these terms are 0.

5.99

$$(a) \quad \text{HHV} = 15,544 (.80) + 62,028 \left(0.0003 - \frac{0.005}{8} \right) + 4050(0.006)$$

$$= 11,800 \text{ Btu/lb}$$

$$\text{LHV} = 11,800 - 91(0.3) = 11,770 \text{ Btu/lb}$$

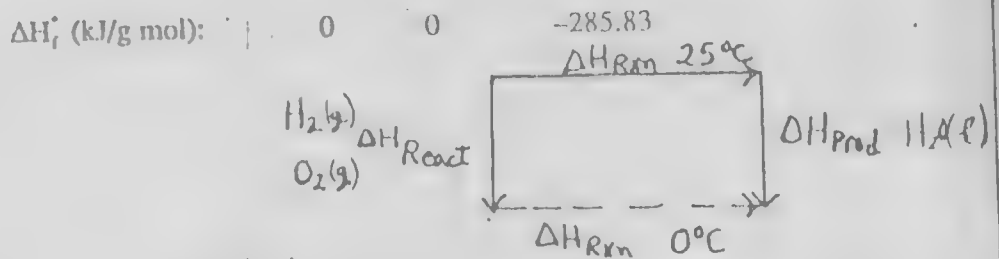
$$(b) \quad \text{HHV} = 17,887 + 51.7(30) - 102.2(0.5) = 19,560 \text{ Btu/lb}$$

$$\text{LHV} = 19,560 - 91.23(12.05) = 18,460 \text{ Btu/lb}$$

5.100

If the fuel cannot produce H_2O as a product, HHV = LHV, but the concept really refers to cases in which water is produced so that HHV $\neq$ LHV.

5.101

Basis: 1 g mol $\text{H}_2(\text{g})$

$$\Delta H_{R_{\text{xn}}}(0^\circ\text{C}) = \Sigma \Delta H_{\text{Products}} - \Sigma \Delta H_{\text{Reactants}}$$

$$\Sigma \text{Products} = (-285.83) + \int_{25^\circ\text{C}}^{0^\circ\text{C}} \frac{4.184 \text{ J}}{(\text{g})(^\circ\text{C})} \left| \frac{18 \text{ g H}_2\text{O}}{\text{g mol}} \right| dT = -287.71 \text{ kJ}$$

$$\Sigma \text{Reactants} = (0 + 0) + (1) \int_{25^\circ\text{C}}^{0^\circ\text{C}} (28.84 + 0.00765 \times 10^{-2} T) dT$$

$$+ \left(\frac{1}{2}\right) \int_{25^\circ\text{C}}^{0^\circ\text{C}} (29.10 + 1.158 \times 10^{-2} T) dT = -1.45 \text{ kJ}$$

$$\Delta H_{R_{\text{xn}}}(0^\circ\text{C}) = -287.71 - (-1.45) = \boxed{-286.26 \text{ kJ}}$$

5.102

Basis: 100 lb mol gas

Comp.	mol	$\Delta \hat{H}/\text{lb mol}$	Total Btu
CO_2	9.2	0	0
C_2H_4	0.4	598,000	239,000
CO	20.9	122,000	2,544,000
H_2	15.6	123,000	1,918,000
CH_4	1.9	383,000	728,000
N_2	52.0	0	0
	100.0		5,429,000

$$\frac{\text{Btu}}{\text{ft}^3} = \frac{5,429,000 \text{ Btu}}{100 \text{ lb mol}} \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \frac{520^\circ\text{R}}{492^\circ\text{R}}$$

$$= \boxed{143 \text{ Btu / ft}^3 \text{ at std. conditions of NGI}}$$

5.103

Basis: 1 g mol isopropyl benzene C_9H_{12} - C_9H_9 - C_9H_{12} 

The higher heating value is with H_2O as a liquid. Also, at $25^\circ C$, C_9H_{12} is a liquid; its normal boiling point is 432 K.

$$\Delta \hat{H}_f^\circ \left(\frac{kJ}{g \text{ mol}} \right): \quad -38.40 \quad 0 \quad -393.51 \quad -285.840$$

$$\begin{aligned} \Delta \hat{H}_{rxn}^\circ &= [6(-285.840 + 9(-393.51))] - [(1)(-38.40)] \\ &= \boxed{-5218.2 \text{ kJ/g mol } C_9H_{12}} \end{aligned}$$

Presumably the humidity referred to in the problem refers to the final humidity of the water-air mixture after combustion, but all the water is assumed to be liquid for the HHV. If the heating value were measured experimentally with 40% relative humidity, a slight correction would be needed to get the HHV.

5.104

Basis: 100 mol of gas

(a₁)

Comp.	mol.wt.	Mol% = Vol.%	lb	$-\Delta H_{c1}^\circ$ kJ/g mol	$-\Delta H_{c2}^\circ$ kJ/g mol
CH ₄	16	88	1408	890.35	802.32
C ₂ H ₆	30	6	180	1559.88	1427.84
C ₃ H ₈	44	4	176	2220.05	2044.00
C ₄ H ₁₀	58	2	116	2878.52	2658.45
Total		100	1880		

$$\text{mol. wt. mixture} = 18.80 \text{ lb/lb mol}$$

$$-\Delta H_{c1}^\circ = H_2O (l) \text{ to } CO_2 (g) \text{ products; } -\Delta H_{c2}^\circ = H_2O (g) + CO_2 (g) \text{ products}$$

$$\Delta H_{rxn}^\circ = -[\Delta H_c \text{ prod} - \Delta H_c \text{ react}] = 1022.90 \text{ kJ/g mol}$$

$$\Delta H_{rxn}^\circ = \frac{-1022.90}{g \text{ mol}} \left| \frac{454 \text{ g mol}}{lb \text{ mol}} \right| \left| \frac{Btu}{1.055 \text{ kJ}} \right| \left| \frac{lb \text{ mol}}{18.80 \text{ lb}} \right| = \boxed{-23,600 \frac{Btu}{lb}}$$

$$(a_2) : \Delta H_{rxn}^\circ = (-23,600) (18.80) = \boxed{-439,000 \text{ Btu/lb mol}}$$

(continued)

Solutions-Chapter-5

$$(a_3) \quad \Delta H^\circ_{\text{rxn}} = \frac{-439,000 \text{ Btu}}{\text{lb mol}} \left| \frac{1 \text{ lb mol}}{379.2 \text{ ft}^3 \text{ at } 60^\circ\text{F, } 760 \text{ mm Hg}} \right|$$

$$= \boxed{1160 \text{ Btu / ft}^3 \text{ at } 60^\circ\text{F, } 760 \text{ mm Hg}}$$

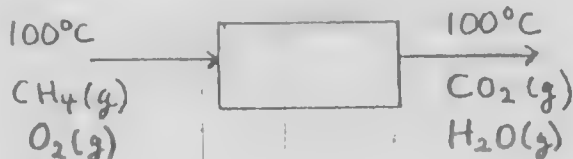
$$(b_1) \quad \Delta H^\circ_2 \text{ rxn} = -925.71 \text{ kJ/g mol}$$

$$\Delta H^\circ_2 \text{ rxn} = \frac{-925.71}{1.055} \left| \frac{454}{18.80} \right| = -21,200 \text{ Btu/lb}$$

$$(b_2) \quad \Delta H^\circ_2 \text{ rxn} = (-21,200) (18.80) = \boxed{398,000 \text{ Btu / lb mol}}$$

$$(b_3) \quad \Delta H^\circ_2 \text{ rxn} = (-398,000)/(379.2) = \boxed{1051 \text{ Btu / ft}^3 \text{ at } 60^\circ\text{F and } 760 \text{ mm Hg}}$$

5.105



Basis: 1 g mol CH_4

$$\Delta H_{\text{Rxn}} = \sum \Delta H_{\text{Products}} - \sum \Delta H_{\text{Reactants}}$$

100°C

$$= \left[(\Delta \hat{H}_{f, \text{H}_2\text{O}}^\circ) 2 + (\Delta \hat{H}_{f, \text{CO}_2}^\circ) (1) + (\Delta \hat{H}_{\text{Sensible heat, CO}_2}) (1) \right]$$

$$+ (\Delta \hat{H}_{\text{Sensible heat, H}_2\text{O}}) 2] - \left[(\Delta \hat{H}_{f, \text{CH}_4}^\circ) 1 + \text{O}(2) \right]$$

$$+ (\Delta \hat{H}_{\text{Sensible heat, CH}_4}) 1 + (\Delta \hat{H}_{\text{Sensible heat, O}_2}) (2)]$$

$$= -822.66 \text{ kJ}$$

Use the tables in the Appendix to get values for $\Delta \hat{H}_f^\circ$ and also for the sensible heats (or integrate the heat capacity equations to get the sensible heats).

- 5.106 It does not mean that the work that could be done is more. Probably it means that the total heat of combustion of the products in the pipeline per unit time is less than the heat transferred through window per the same unit time.

- 5.107 Assume that the furnace has to be ready to function at the operating temperature after 48 hours.

<u>Oil reqd</u>		<u>L used</u>
Operating for 48-hours:	270(48)=	12,960
Heating:	6.5(760) =	<u>4,940</u>
Difference		<u>8,020</u> × .16 = \$1,280
Operating for 24 hours:	270(24) =	6,480
Heating:		<u>4,940</u>
		<u>1,540</u> × .16 = \$ 250

The problems may have to do with excessive maintenance on shutting the furnace down and starting it up. The insulation may be damaged.

- 5.108 The problem requires more information to solve. To make the solution easier but approximate, assume the reaction takes place at 25°C and 1 atm. Assume that the energy balance reduces to $Q = \Delta H$, and that Q represents the desired kJ. Data: $\Delta \hat{H}_f^\circ \text{H}_2\text{O} = -285.840$ $\Delta \hat{H}_f^\circ \text{CO}_2 = -393.51$, both in kJ/g mol. Ref. temp. = 250°C. Basis: 1 g mol glucose. MW of glucose = 180.

$$\Delta H^\circ = \Delta H_{\text{products}}^\circ - \Delta H_{\text{reactants}}^\circ$$

$$= [6(-285.840) + 6(-393.51)] - [1(-1260) + 6(0)] = -2816 \text{ kJ}$$

$$\frac{0.90(-2816)}{180} = 14.0 \text{ kJ/g glucose}$$

At 37°C (body temperature), assume only the O_2 is used in a reaction

$$\frac{0.90}{1 \text{ g mol suc.}} \left| \frac{6 \text{ g mol O}_2}{\text{g mol O}_2} \right| \frac{22.4 \text{ L at SC}}{\text{g mol O}_2} \left| \frac{310 \text{ K}}{273 \text{ K}} \right| \frac{1 \text{ g mol suc.}}{180 \text{ g suc.}} = 0.76 \text{ L/g at } 37^\circ\text{C and } 1 \text{ atm}$$



Basis: 1 g mol butane

$$Q = \Delta H_{\text{Prod.}} - \Delta H_{\text{React.}}$$

$$\Delta \hat{H}_f^\circ(\text{C}_4\text{H}_6) = -165.5 \text{ kJ/g mol}$$

$$\Delta \hat{H}_f^\circ(\text{C}_4\text{H}_{10})_{\text{liquid}} = -147.6 \text{ kJ/g mol}$$

Sensible heats:

$$\Delta H = \int_{298}^{1000} C_p dT$$

$$C_p = a + bT + cT^2 + dT^3$$

$$\therefore \Delta H = aT + \frac{b}{2}T^2 + \frac{c}{3}T^3 + \frac{d}{4}T^4$$

$$\Delta H_{\text{C}_4\text{H}_6} = 11.92T + 1.346 \times 10^{-1}T^2 - 4.767 \times 10^{-5}T^3 + 7.368 \times 10^{-9}T^4 \Big|_{298}^{1000}$$

$$\Delta H_{\text{C}_4\text{H}_6} = 91.92 \text{ kJ}$$

$$\Delta H_{\text{C}_4\text{H}_{10}} = 92.3T + 1.394 \times 10^{-1}T^2 - 5.157 \times 10^{-5}T^3 + 8.745 \times 10^{-9}T^4 \Big|_{25}^{727}$$

$$\Delta H_{\text{C}_4\text{H}_{10}} = 121.0 \text{ kJ}$$

$$\Delta H_2 = 28.84T + 3.825 \times 10^{-5}T^2 + 1.096 \times 10^{-6}T^3 - 2.175 \times 10^{-10}T^4 \Big|_{25}^{727}$$

$$\Delta H_2 = 20.63 \text{ kJ}$$

$$\Sigma \Delta H_{\text{prod}} = \Delta H_{\text{C}_4\text{H}_6} + 2\Delta H_{\text{H}_2} = 91.92 + 2(20.63) = 133.18$$

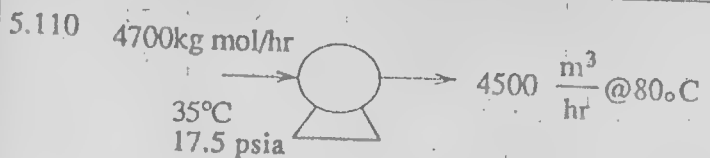
$$\Sigma \Delta H_{\text{react}} = \Delta H_{\text{C}_4\text{H}_{10}} = 121.0 \text{ kJ}$$

Heat Transfer:

$$\text{So } \Delta H_{1000} = [(-165.5) - (-147.6)] + 133.18 - 121.0 = \boxed{5.72 \text{ kJ/g mol}}$$

The actual heat load may be different because:

- (1) the reaction may not go to completion
- (2) side reactions are possible
- (3) the effect of pressure is not included
- (4) insulation may be bad



(a) Basis: 1 cubic ft of feed gas at feed conditions:

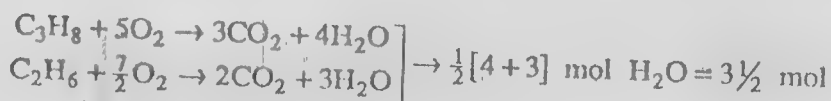
$$n = \frac{pV}{RT} = \frac{17.5(1)(\text{ft}^3)(\text{psia})}{10.73(308) \times 1.8 \frac{(\text{ft}^3)(\text{psia})}{\text{lb mol}}} = 2.94 \times 10^{-3} \text{ lb mol}$$

$$\text{We have } 2.94 \times 10^{-3} \frac{\text{lb mol}}{\text{ft}^3} \left| \frac{454 \text{ g mol}}{\text{lb mol}} \right| = 1.335 \text{ g mol}$$

Thus for a 50/50 mixture

$$\text{HHV} = 0.5(\Delta H_{\text{c}, \text{C}_3} + \Delta H_{\text{c}, \text{C}_2}) = -0.5(2220.0 + 1559.98) \frac{\text{kJ}}{\text{mol}}$$

$$\text{HHV} = -1889.95 \frac{\text{kJ}}{\text{mol}}$$



$$\Delta H_{\text{f}, \text{H}_2\text{O}(\text{g})} - \Delta H_{\text{f}, \text{H}_2\text{O}(\text{l})} = 44.014 \text{ kJ/mol}$$

$$\text{So LHV} = -1889.95 + 3.5(44.014) = -1735.9 \text{ kJ/mol}$$

$$\text{Thus LHV} = -1735.9 (1.335) \frac{(\text{kJ})(\text{g mol})}{(\text{g mol})(\text{ft}^3)} \rightarrow \text{LHV} = -2317.4 \text{ kJ/ft}^3$$

$$\text{At the exit, } 4500 \frac{\text{m}^3}{\text{hr}} \text{ for } 4700 \text{ kg mol} \rightarrow \frac{4500 \text{ m}^3}{4700 \text{ kg mol}} = 0.9574 \frac{\text{m}^3}{\text{kg mol}}$$

$$\text{Thus } V_r = \frac{\hat{V}}{V_{\text{c}, \text{m}}} \text{ and } V_{\text{c}, \text{m}} = \frac{RT_{\text{cm}}}{P_{\text{cm}}}; \quad T_{\text{cm}} = 0.5[370 + 305] = 337.5 \text{ K}$$

$$P_{\text{cm}} = 0.5[42 + 45] = 43.5 \text{ atm}$$

(continued)

Solutions-Chapter-5

$$V_{t,m} = \frac{82.057(337.5)}{43.5} = 636.6 \frac{\text{cm}^3}{\text{mol}}$$

$$V = 0.9574 \frac{\text{m}^3}{\text{kg mol}} \left| \frac{1 \text{ kg mol}}{1000 \text{ mol}} \right| \left| \frac{10^6 \text{ cm}^3}{1 \text{ m}^3} \right| = 957.4 \frac{\text{cm}^3}{\text{mol}}$$

$$V_t = \frac{957.4}{636.6} = 1.504$$

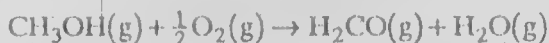
$$@ \text{ Tr} = \frac{90 + 273}{337.5} = 1.046 \rightarrow \text{from low pressure compressibility}$$

$$\text{chart @ } V_{t_i} = 1.504 \text{ and } \text{Tr} = 1.05, p_r = 0.57$$

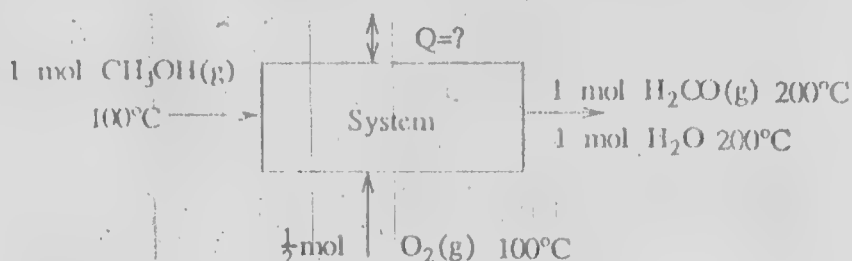
$$\text{Thus } p = 0.57(43.5) = \boxed{24.89 \text{ atm}}$$

5.111 Steps 1, 2, 3, and 4

This is a steady state problem involving an open system and reaction. All the temperatures for the stream flows are given and shown in the diagram. The reaction is



$$\Delta \hat{H}_f^\circ (\text{kJ/gmol}): \quad -201.25 \quad 0 \quad -115.89 \quad -241.826$$



The results of the material balance are shown in the figure. The reference conditions are 25°C and 1 atm.

Step 5 Basis: 1 g mol $\text{CH}_3\text{OH}(\text{g})$

Steps 6, 7, 8, and 9

The energy balance reduces to

$$Q = \Delta H = \sum n_i \Delta \hat{H}_i - \sum n_i \Delta \hat{H}_i$$

products reactants

We will use the heat capacity equations to calculate the sensible heats instead of the enthalpy tables.

(continued)

$$\Delta H_{\text{Products}} = 1 \left[-115.89 + \int_{25}^{200} (33.46 + 0.688 \times 10^{-2} T + 0.7604 \times 10^{-5} T^2 - 3.593 \times 10^{-9} T^3) dT \right]$$

$$= -115.89 + [5999 + 840.26 - 3.477]$$

$$= -241.826 + [5855.5 + 135.45 + 20.238 - 1.43]$$

$$= -344.87 \text{ kJ}$$

$$\Delta H_{\text{Reactants}} = 1 \left[-201.25 + \int_{25}^{100} (42.93 + 8.301 \times 10^{-2} T - 1.87 \times 10^{-5} T^2 - 8.03 \times 10^{-9} T^3) dT \right]$$

$$+ \frac{1}{2} \left[0 + \int_{25}^{100} (29.10 + 1.158 \times 10^{-2} T - 0.6076 \times 10^{-5} T^2 + 1.311 \times 10^{-9} T^3) dT \right]$$

$$= 1[-201.25 + (3219.75 + 389.109 - 6.136 - 0.19996)]$$

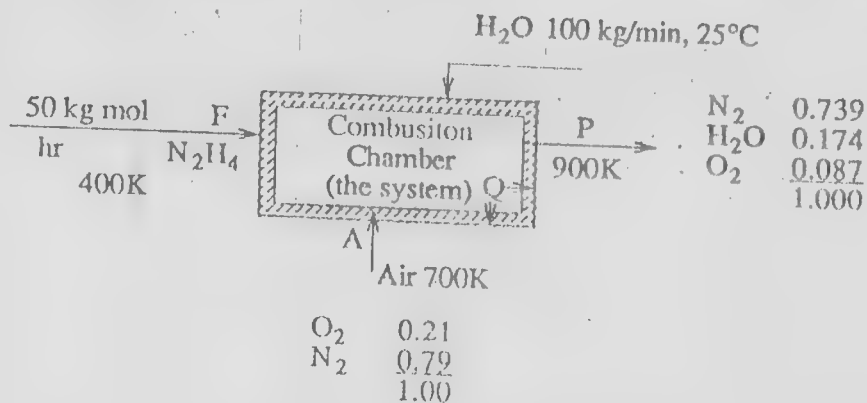
$$+ \frac{1}{2}[0 + (2182.5 + 54.281 - 1.994 + 0.03265)]$$

$$= -197.64 \text{ kJ}$$

$$Q = -344.87 - (197.64) = \boxed{-147.23 \text{ kJ/g mol CH}_3\text{OH}}$$

5.112 Steps 1, 2, 3, and 4

This is a steady state problem involving an open system and reaction. All the known data has been placed in the figure. The surroundings are a open system comprised of the water



Step 5

Basis: 1 hour

(continued)

Solutions-Chapter-5

Step 4

The reaction is



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}): \quad 44.77 \quad 0 \quad 0 \quad -241.826$$

The essential elements of the calculation of the air flow are:

$$\text{O}_2 \text{ required: } \frac{50 \text{ kg mol N}_2\text{H}_4}{1 \text{ kg mol N}_2\text{H}_4} \left| \frac{1 \text{ kg mol O}_2}{1 \text{ kg mol N}_2\text{H}_4} \right| = 50 \text{ kg mol O}_2$$

$$\text{O}_2 \text{ supplied: } \frac{50 \text{ kg mol O}_2 \text{ reqd}}{1 \text{ kg mol O}_2 \text{ reqd}} \left| \frac{2 \text{ kg mol O}_2 \text{ supplied}}{1 \text{ kg mol O}_2 \text{ reqd}} \right| = 100 \text{ kg mol O}_2$$

$$\text{N}_2 \text{ Supplied: } \frac{100 \text{ kg mol O}_2}{0.21 \text{ kg mol O}_2} \left| \frac{0.79 \text{ kg mol N}_2}{0.21 \text{ kg mol O}_2} \right| = 376.2 \text{ kg mol N}_2$$

$$\text{Air Supplied} = 476.2 \text{ kg mol}$$

Steps 5, 6, 7, 8 and 9

The material balances (in kg mol) for the process give for the products:

Balance	In	=	Out
O	200	=	$n_{\text{H}_2\text{O}} + 2n_{\text{O}_2}$
N	$50(2) + 2(376.3)$	=	$n_{\text{N}_2}(2)$
H	$50(4)$	=	$n_{\text{H}_2\text{O}}(2)$

Out (kg mol)

$$n_{\text{H}_2\text{O}} = 100$$

$$n_{\text{N}_2} = 426.2$$

$$n_{\text{O}_2} = 50$$

$$\text{Total} = 576.2$$

The energy balance can be reduced to $Q = \Delta H$ for both the water and the combustion chamber. The reference state is 25°C and one atm.

(continued)

System: Combustion Chamber

$$Q = \Delta H_{\text{products}} - \Delta H_{\text{reactants}} = \sum_{\text{products}} n_i \Delta \hat{H}_i - \sum_{\text{reactants}} n_i \Delta \hat{H}_i$$

We can use the heat capacity equations or the enthalpy tables to get $\Delta \hat{H}_i$.

Products	kg mol	T	$\Delta \hat{H}_i^0$ (kJ/kg mol)	$\Delta \hat{H}_{298K}^{900K}$ (kJ/kg mol)	ΔH (kJ)
H ₂ O(g)	100	900K	-421,826	(22,760-837)	-3.999×10^7
N ₂ (g)	426.2	900K	0	(18,961-728)	0.777×10^7
O ₂ (g)	50	900K	0	(19,970-732)	0.096×10^7
Total					-3.126×10^7

Reactants	kg mol	T	$\Delta \hat{H}_i^0$ (kJ/kg mol)	$\Delta \hat{H}_{25}^T$ (kJ/kg mol)	ΔH (kJ)
N ₂ H ₄ (g)	50	400K	+44,770	139(400-298)	2.9474×10^6
O ₂ (g)	100	700K	0	(13,225-732)	12.493×10^6
N ₂ (g)	376.2	700K	0	(12,652-728)	4.4885×10^6
Total					$19.929 \times 10^6 \text{ kJ}$

$$Q = ((-31.26) - (-19.929)) \times 10^6 = -11.33 \times 10^6 \text{ kJ (heat leaving the system is negative)}$$

System: Water (6000 lb/hr)

$$\Delta H = Q = 11.331 \times 10^6 \text{ kJ} \quad \Delta \hat{H}_{in} \text{ at } 25^\circ\text{C} = 103 \text{ kJ/kg}$$

$$\Delta H_{out} = \Delta H_{in} + 11.33 \times 10^6 \text{ kJ} = 6000(103) + 11.331 \times 10^6 = 11.34 \times 10^6 \text{ kJ}$$

$$\Delta \hat{H}_{out} = \frac{10.731 \times 10^6}{6000} = 1.789 \times 10^3 \text{ kJ/kg H}_2\text{O}$$

From the steam tables at 1 atm, $\Delta \hat{H}$ of saturated water vapor is 2675.6 kJ/kg, and $\Delta \hat{H}$ for liquid water is 419.5. Thus, the fraction vapor is

$$1,789 = 419.5(1-x) + 2675.6x$$

$$x = 0.61, \text{ a significant fraction.}$$

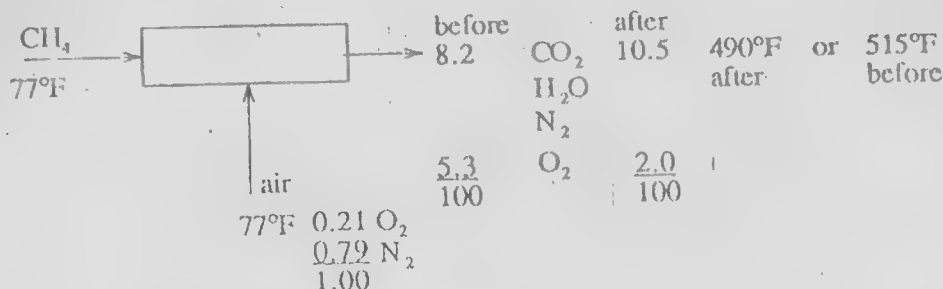
(continued)

Solutions-Chapter-5

5.113 Material balance

Assume inputs are at 77°F.

Basis: 100 mol fg.



2% O₂ in fg. corresponds to 10% excess air }
5.3% O₂ in fg. corresponds to 30% excess air }

Difference gases 2.3% reduction is CH₄ usage

Energy balance

Basis: 1 year

$$\frac{890.4 \text{ kJ}}{\text{g mol}} \left| \frac{1 \text{ Btu}}{1.055 \text{ kJ}} \right| \frac{454 \text{ g mol}}{1 \text{ lb mol}} \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3 \text{ at SC}} \right| \frac{1.8 \times 10^5 \text{ ft}^3}{\text{hr}} \left| \frac{8000 \text{ hr}}{\text{yr}} \right|$$

$$\times \frac{\$1.55}{10^6 \text{ Btu}} \left| \frac{0.023}{1} \right| = \$54,790 / \text{yr.} \quad \frac{31,000}{54,790} = \boxed{0.57 \text{ yr}}$$

for payoff

5.114 1.

First, we estimate the heat recovery from the exhaust gas when cooled from 1100°F to 350°F, which is 100°F above the temperature of 15 psig saturated steam.

From the tables with the initial and final exhaust gas temperatures, 1100°F and 350°F respectively, we determine the approximate heat recovery to be 198 Btu/lb exhaust gas.

Knowing that the specific volume of the flue gas (the specific volume of flue gas at a given temperature is very close to the specific volume of air at that temperature.) at 1100°F is 39.5 cu ft/lb, we convert the exhaust flow rate from 4225 cfm to lb/h as follows:

$$\text{Exhaust flow rate} = \frac{4225 \text{ (cu ft/min)} \times 60 \text{ (min/hr)}}{39.5 \text{ cu ft/lb}}$$

$$= 6420 \text{ lb/h}$$

$$\begin{aligned} \text{Then, rate of heat recovery} &= 6420 \text{ lb/h} \times 198 \text{ Btu/lb} \\ &= 1.27 \text{ MBtu/hr} \end{aligned}$$

(continued)

2. Next, we calculate the amount of steam generated from the exhaust heat recovered. We determine that with 220°F feedwater the heat absorbed in generating 15 psig saturated steam is 977 Btu/lb steam.

$$\text{Steam generation} = \frac{1.27 \text{ MBtu/hr}}{977 \text{ Btu/lb}} = 1300 \text{ lb/hr}$$

Thus, steam generation from the fired boiler is reduced from 2000 lb/h to 700 lb/hr.

3. The resulting annual fuel savings with 80% boiler efficiency based on the lower heating value of the #2 fuel oil (18,300 Btu/lb oil) and assuming 4500 hours of operation per year are calculated below:

$$\begin{aligned} \text{Annual fuel savings} &= \frac{1.27 \text{ MBtu/hr} \times 4500 \text{ hr/yr}}{0.8} \\ &= \boxed{7140 \text{ MBtu/yr}} \end{aligned}$$

Knowing that the fuel oil density is about 7.02 lb/gal, we figure the annual fuel savings in gallons.

$$\begin{aligned} \text{Annual fuel savings} &= \frac{7140 \text{ MBtu/yr}}{18,300 \text{ Btu/lb} \times 7.02 \text{ lb/gal}} \\ &= \boxed{55,600 \text{ gal/yr}} \end{aligned}$$

4. If the #2 fuel oil costs \$0.50/gal,

$$\begin{aligned} \text{Annual savings} &= 55,600 \text{ gal/yr} \times \$0.50/\text{gal} \\ &= \boxed{\$27,800 \text{ per year}} \end{aligned}$$

The total cost of a waste heat recovery muffler and installation is about \$20 000 for a 500 hp engine. In this case, the installation can be paid off in about two to three years.

5.115

Basis: 10.0 min

The thermodynamic properties are from the Chemical Engineer's Handbook. The attached plot is used for quicker interpolation using °F instead of K for temperature. The data for n-G based on liquid Cp's and ΔH's have been extrapolated from the handbook data.

The hot liquid will flash with no change in total enthalpy. Thus, the fraction vaporized will be

(continued)

Solutions-Chapter-5

$\dot{V}$ = Vapor rate

$\dot{F}$ = Spill (feed) rate

$$\frac{\dot{V}}{\dot{F}} = \frac{h_F - h_L}{H_V - h_L}$$

h_F = Enthalpy of spilled liq

h_L = Enthalpy of flashed liq

H_V = Enthalpy of flashed vap

$\dot{V}$ and $\dot{F}$ have mass or mole units

Specific gravity of solvents at 400°F:

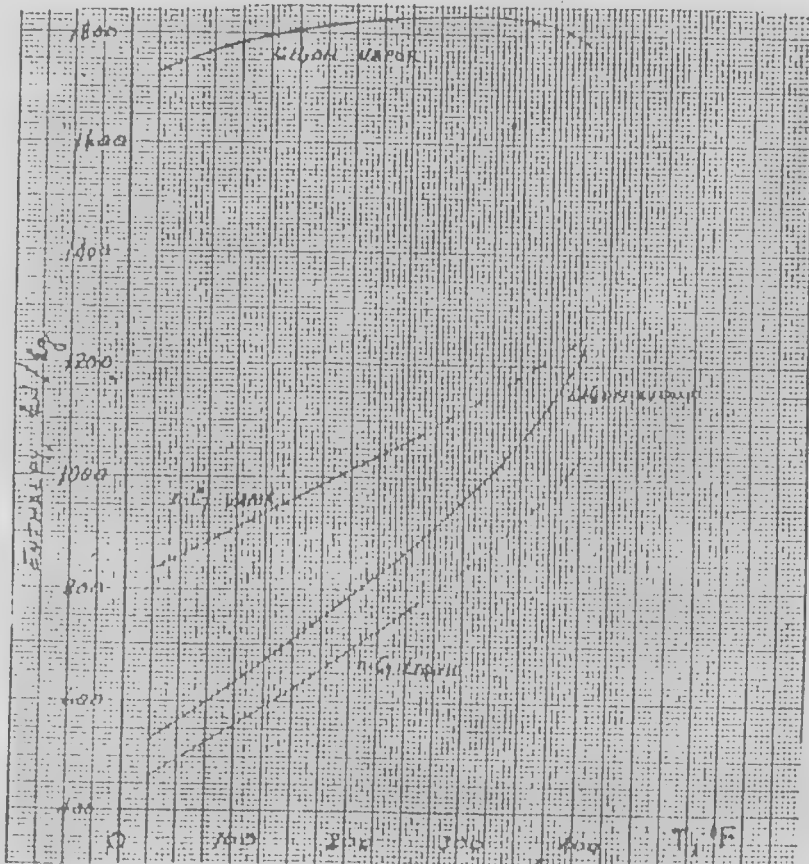
CH_3OH : 0.529

$n\text{-C}_7$: 0.489

Spill Rates:

$$\text{CH}_3\text{OH} \quad 1000 \frac{\text{gal}}{\text{min}} (0.529)(8.35) \frac{\text{lb}}{\text{gal}} = 4417 \frac{\text{lb}}{\text{min}}$$

$$n\text{-G} \quad 1000 \frac{\text{gal}}{\text{min}} (0.489)(8.35) \frac{\text{lb}}{\text{gal}} = 4083 \frac{\text{lb}}{\text{min}}$$



(continued)

		h_F	h_L	H_v	$\dot{V}$	
			kJ/kg		lb/min	
CH ₃ OH	25°F	1210	530	1730	2503	
	80°F	1210	605	1770	2793	
BP	148°F	1210	708	1805	2021	
nG	25°F	1030	465	840	4083	(all vapor)
	80°F	1030	542	890	4083	(all vapor)
BP	209°F	1030	701	1022	4083	(all vapor)

(Note that all the n-heptane always flashes to vapor. Hydrocarbons generally have low heats of vaporization.)

The lower flammable limits of the solvents are

$$\text{For } \text{CH}_3\text{OH} \rightarrow 6.7\% \quad n-G \rightarrow 1.05\%$$

The volume of vapor is

v_v = specific volume of vapor

$$V_v = \dot{V} t v_s$$

t = spill time

and the volume of the maximum flammable vapor cloud is

$$\frac{V_v}{\text{LFL}} = \frac{\dot{V} t v_v}{\text{LFL}}$$

Using v_v at 80°F

$$v_v = \frac{RT}{p} = \frac{(10.73)(\text{ft}^3)(\text{psia})(540)(^\circ\text{R})}{(\text{lb mol})(^\circ\text{R})(14.7)(\text{psia})(32)(\text{lb})} \quad (\text{lb mol})$$

$$= 12.32 \frac{\text{ft}^3}{\text{lb}} \text{ for CH}_3\text{OH}$$

$$v_v = \frac{(10.73)(540)}{(14.7)(98)} = 4.02 \frac{\text{ft}^3}{\text{lb}} \text{ for n-G}$$

The vapor cloud volumes are:

for CH₃OH at 80°F

$$\frac{(2293)\text{lb}(10)\text{min}(12.32)\text{ft}^3}{(\text{min})(\text{lb})(0.067)} = \boxed{4.22(10^6)\text{ft}^3}$$

(continued)

Solutions-Chapter-5

for n-G

$$\frac{(4083)(10)(4.02)}{(0.0105)} = \boxed{15.6(10^6) \text{ ft}^3}$$

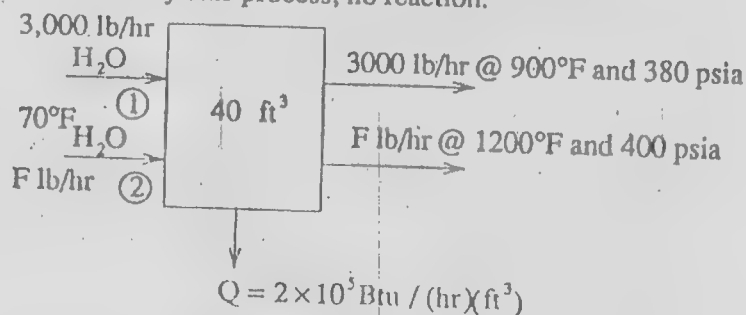
Therefore, choose methanol

	$n\text{C}_7$	CH_3OH	
heats of combustion are	19,157	8,592	Btu/lb
mass burned	4,083	2,503	lb
energy released	78(10 ⁶)	21(10 ⁶)	Btu

So, still choose CH_3OH .

- 5.116 (a) reduces
(b) increases
(c) reduces

5.117 Steady state process, no reaction.



Basis: $Q = (2 \times 10^5)(40) = 8 \times 10^6 \text{ Btu} \equiv 1 \text{ hour}$

The energy balance is: $Q = \Delta H$

In

	mass (lb)	$\hat{\Delta H}(\text{Btu/lb})$	$\Delta H(\text{Btu})$
①	3000 (satd)	38.05	1.14×10^5
②	F (satd)	38.05	$38.05F$

Out

①	3000	1469.2	4.408×10^6
①	F	1628.8	$1628.8F$

$$\Delta H_{\text{out}} - \Delta H_{\text{in}} = Q$$

$$(1628.8F + 4.408 \times 10^6) - (38.05F + 1.14 \times 10^5) = 8 \times 10^6$$

$$\boxed{F = 2,816 \text{ lb/hr}}$$

5.118

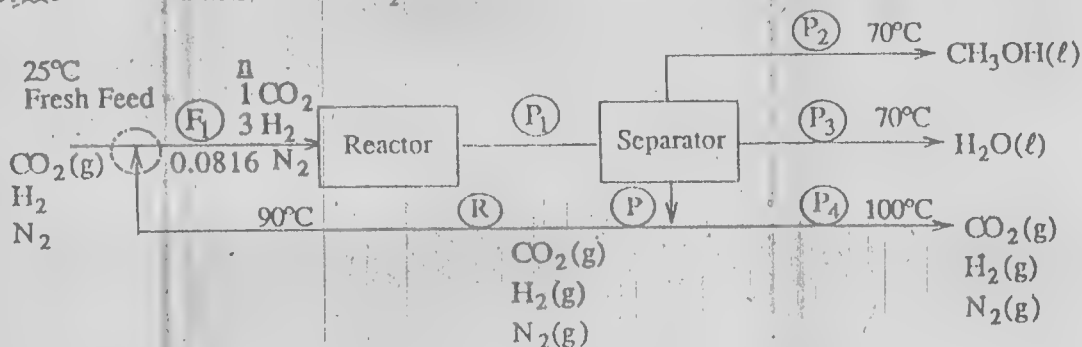

 $\Delta \hat{H}_{Rxn}^\circ$ is at 25°C, 1 atm

$$\Delta \hat{H}_{Rxn}^\circ = \sum_{\text{prod.}} \Delta \hat{H}_f^\circ - \sum_{\text{react.}} \Delta \hat{H}_f^\circ = (1.040 \times 10^9 - 0.990 \times 10^9) \text{ J/g mol G}$$

$$= 50 \times 10^6 \text{ J/g mol G converted}$$

$$\text{Since 0.48 reacts, } \Delta \hat{H}_{Rxn}^\circ = 0.48(50) \times 10^6 \text{ J/g mol G}$$

$$= 24 \times 10^6 \text{ J/g mol G fed (not asked for)}$$

119
5.120Basis: 1 mol CO₂ in Gross Feed

$$25^\circ\text{C} = 298\text{K} \quad 70^\circ\text{C} = 343\text{K} \quad 100^\circ\text{C} = 373\text{K}$$

Material BalancesN₂ in gross feed to the reactor

$$0.02 = \frac{n_{\text{N}_2}}{1 + 3 + n_{\text{N}_2}} \quad n_{\text{N}_2}^{\text{F}} = 0.0816 \text{ mol}$$

System: Reactor plus separator

	$\textcircled{F_1}$	=	$\textcircled{P_2}$	+	$\textcircled{P_3}$	+	$\textcircled{P}$
C:	1	=	P ₂ (1)	+	0	+	$n_{\text{CO}_2}^{\text{P}}$
H:	3(2)	=	P ₂ (4)	+	2P ₃	+	$n_{\text{H}_2}^{\text{P}}(2)$
O:	1(2)	=	P ₂ (1)	+	P ₃ (1)	+	$n_{\text{CO}_2}^{\text{P}}(2)$
N ₂	0.0816	=	P ₂ (0)	+	P ₃ (0)	+	$n_{\text{N}_2}^{\text{P}}$

(continued)

	in	-	out	+ gen	-	consumed
CO ₂ balance:	1	-	$n_{\text{CO}_2}^P$	+ 0	-	0.57(1)

Unknowns: $P_2, P_3, n_{\text{CO}_2}^P, n_{\text{H}_2}^P, n_{\text{N}_2}^P$ (5)

balances: (5)

After F and R are calculated as below $F = F_1 - R$

$$n_{\text{CO}_2}^F = 1 - (0.43 - 0.067) = 0.503$$

$$n_{\text{H}_2}^P = 3 - (1.29 - 0.336) = 1.374$$

$$n_{\text{N}_2}^F = 0.0816 - (0.0816 - 0.0128) = 0.0128 \quad \text{check} \quad \frac{0.0128}{2.502} = 0.005$$

moles

$$n_{\text{CO}_2}^P = 0.43$$

$$n_{\text{H}_2} = 1.29$$

$$P_2 = 1 - 0.43 = 0.57 \quad (\text{CH}_3\text{OH})$$

$$P_3 = 0.57 \quad (\text{H}_2\text{O})$$

$$n_{\text{N}_2}^P = 0.0816$$

$$P = 0.43 + 1.29 + 0.0816$$

$$= 1.802$$

To get inputs make

System: mixing point before reactor

$$\text{Total: } F + R = 4.0816$$

$$\text{N}_2: 0.005F + x_{\text{N}_2}^R R = 0.0816$$

$$x_{\text{N}_2}^R = \frac{0.0816}{0.43 + 1.29 + 0.0816} = 0.0453$$

moles

$$F = 2.562$$

$$R = 1.520$$

$$n_{\text{N}_2}^R = x_{\text{N}_2}^R R = 0.06$$

System: sep. point after separator

$$P_4 = P - R \text{ \& for each component}$$

$$P_4 = 1.802 - 1.520 = 0.282$$

$$n_{\text{CO}_2}^{P_4} = \left(\frac{0.43}{1.802} \right) 0.282 = 0.067$$

$$n_{\text{H}_2}^{P_4} = \left(\frac{1.29}{1.802} \right) 0.282 = 0.336$$

$$n_{\text{N}_2}^{P_4} = \left(\frac{0.816}{1.802} \right) (0.282) = 0.0128$$

(continued)

Energy Balance (ref. 25°C)					
OUT	Comp.	kg moles	$\Delta \hat{H}_f^\circ$	J/g mol $\Delta \hat{H}_{sens.}$	ΔH
70°C	CH ₃ OH(l)	0.57	-277,630	(70-25)(4.184)(.680)(46)	-154,892
70°C	H ₂ O(l)	0.57	-285,840	(70-25)(4.184)(18)	-160,997
100°C	CO ₂ (g) in P ₄	0.067	-393,510	(3045-912)	-26,222
100°C	H ₂ (g) in P ₄	0.336	0	(2874-718)	724
100°C	N ₂ (g) in P ₄	0.0128	0	(2910-728)	28
					<u>-341,359</u>
$\Delta E = Q + W - \Delta H$ $Q = \Delta H = \Delta H_{prod} - \Delta H_{react}$					
IN	25°C CO ₂ (g)	0.503	-393,510	0	-197,936
	25°C H ₂ (g)	1.374	0	0	0
	100°C N ₂ (g)	0.0816	0	0	0
					<u>-197,936</u>

¹²⁰
 5.119 CH₄(g) (F)

50°C
 ↓
 Reactor
 30% conversion

(P)
 200°C
 CH₄(g)
 O₂(g)
 CH₃OH(g)

100°C O₂(g)
 (A)

$$CH_4(g) + \frac{1}{2} O_2(g) \rightarrow CH_3OH(g)$$

$\Delta \hat{H}_f^\circ:$	-17,899	0	-48,100	all cal/g mol
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Basis: 1 g mol CH₄(g)

O₂(g) entering: 0.5 g mol

	in	out	+	gen.	-	cons.	=	
CH ₄ (g)	1	$-n_{CH_4}^p$	+	0	-	0.30(1)	=	0
O ₂ (g)	0.5	$-n_{O_2}^p$	+	0	-	0.30(0.5)	=	0
CH ₃ OH(g)	0	$-n_{CH_3OH}^p$	+	0.30(1)	-	0	=	0

$n_{CH_4}^p = 0.70$
 $n_{O_2}^p = 0.35$
 $n_{CH_3OH}^p = 0.30$

Convert to basis of 100 kg mol CH₃OH produced (all g mol):

(continued)

Solutions-Chapter-5

Out		In	
CH ₄ :	$\frac{0.70}{0.30}(100) = 233.3$	CH ₄ :	$\frac{1}{0.30}(100) = 333.3$
O ₂ :	$\frac{0.35}{0.30}(100) = 116.7$	O ₂ :	$\frac{0.5}{0.30}(100) = 166.7$
CH ₃ OH:	$\frac{0.30}{0.30}(100) = 100.0$		

Energy balance: Steady State, ref. T = 25°C

$$\Delta E = 0 = Q + \cancel{W} - \Delta H \quad \text{so } Q = \Delta H$$

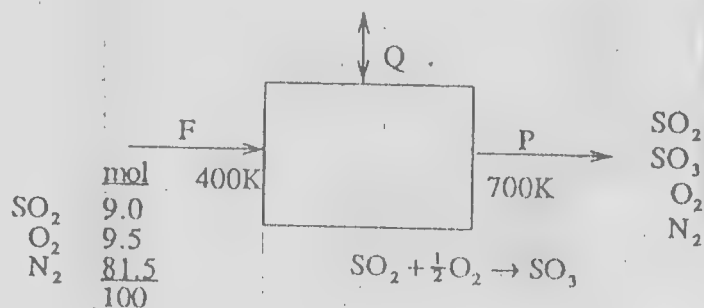
OUT	mol	$\Delta \hat{H}_f^\circ$ (cal/g mol)	T(°C)	$\Delta \hat{H}_{25}^\circ$ (cal/g mol)	ΔH (cal)
CH ₄ (g)	233.3	-17,889	200	(1882 - 210)	-3,783 × 10 ³
O ₂ (g)	116.7	0	200	(1432 - 175)	+ 147 × 10 ³
CH ₃ OH(g)	100.0	-48,100	200	(2434 - 263)	-4,593 × 10 ³
					-8,230 × 10 ³
IN					
CH ₄ (g)	333.3	-17,889	50	(434 - 210)	-5,888 × 10 ³
O ₂ (g)	166.7	0	100	(705.7 - 175)	+ 88 × 10 ³
					-5,799 × 10 ³

$$Q = [(-8,230) - (-5,799)] \times 10^3 = -2,432 \text{ kcal/100 kg mol CH}_3\text{OH}$$

(heat removed)

5.121 Steady state, no W, no P, no K so Q = ΔH

Basis: 100 mol F



(continued)

Material balance

$$S \begin{cases} 9.0(0.75) \\ 9.0(0.25) \end{cases} = n_{SO_2}^P = n_{SO_2}^P \quad \begin{matrix} \text{mol out} \\ 6.75 \\ 2.25 \end{matrix}$$

$$N_2: 81.5 = n_{N_2}^P \quad 81.5$$

$$O_2: 9.0 + 9.5 = n_{SO_2}^P(1.5) + n_{SO_2}^P(1) + n_{O_2}^P(1)$$

$$n_{O_2}^P = 18.5 - 1.5(6.75) - 2.25 = 6.125$$

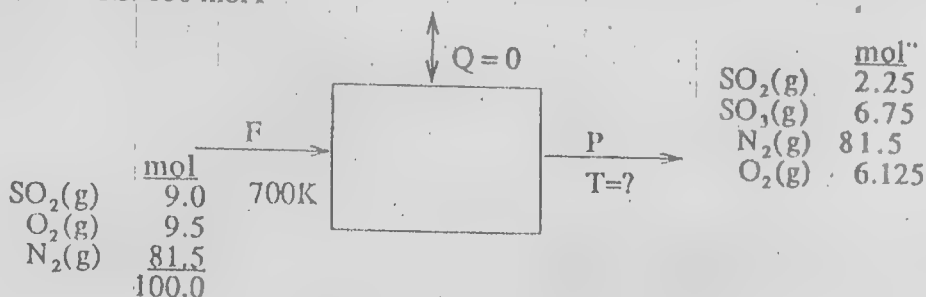
$$\text{Ref. } T = 25^\circ\text{C} = 298\text{K}$$

OUT Component	mol	T(K)	$\Delta \hat{H}_f^\circ$ (J/g mol)	$\Delta \hat{H}$ (J/g mol)	ΔH (J)
SO ₂ (g)	2.25	700K	-296,900	(19,501-984)	-626,361.8
SO ₃ (g)	6.75	700K	-395,180	(27,154-1255)	-2,492,646.8
N ₂ (g)	81.5	700K	0	(12,652-728)	971,806.0
O ₂ (g)	6.125	700K	0	(13,225-732)	76,519.6
					-2,070,683
IN					
SO ₂ (g)	9.0	400K	-296,900	(5,234-984)	-2,633,850
O ₂ (g)	9.5	400K	0	(3,752-732)	28,690
N ₂ (g)	81.5	400K	0	(3,695-728)	241,810.5
					-2,363,349.5

$$Q = [\Sigma \Delta H_{\text{Prod}} - \Sigma \Delta H_{\text{React}}] = 32.52 \frac{\text{kJ}}{\text{g mol}}$$

5.122

Basis: 100 mol F



$$\dot{Q} + \dot{W} = \Delta \dot{H}$$

steady state, flow, no W, P, K; $Q = 0$

$$\Delta H = 0$$

(continued)

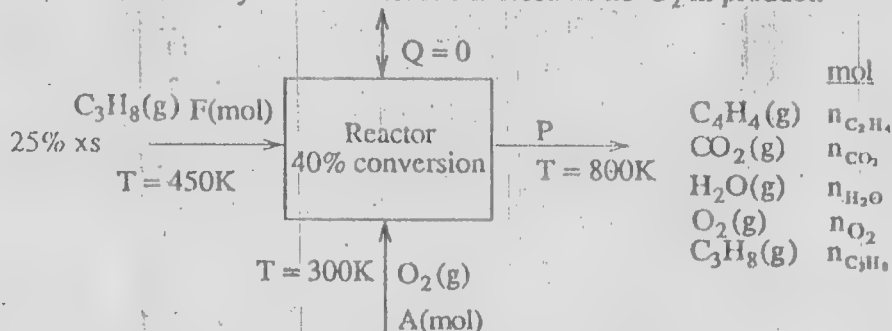
Solutions-Chapter 5

IN						
Component	mol	T(K)	$\Delta \hat{H}_f^\circ$ (J/g mol)	$\Delta \hat{H}$ (J/g mol)	ΔH (J)	
SO ₂ (g)	9.0	700K	-296,900	19,501-984	-2,505,557	
O ₂ (g)	9.5	700K	0	13,225-732	118,688.5	
N ₂ (g)	81.5	700K	0	12,652-728	971,806	
					-1,414,958	
OUT	mol					
			$\Delta \hat{H}_f^\circ$	T	$\Delta \hat{H}$ (J/g mol)	ΔH (J)
SO ₂ (g)	2.25		-296,900	1000K	35,275-984	-590,870
SO ₃ (g)	6.75		-395,180	1000K	50,835-1,255	-233,280
N ₂ (g)	81.5		0	1000K	22,171-728	174,760
O ₂ (g)	6.125		0	1000K	23,434-732	139,050
						-1,037,015
SO ₂ (g)	2.25		-296,900	800K	24,647-984	-614,783
SO ₃ (g)	6.75		-395,180	800K	34,748-1,225	-2,441,185
N ₂ (g)	81.50		0	800K	15,756-728	122,478
O ₂ (g)	6.125		0	800K	16,564-732	96,971
						-1,734,215

By linear interpolation $T \sim 892K$

5.123

Process is steady state with reaction. Assume no O₂ in product.



Step 5: Basis: 100 mol O₂ so F = 50(1.25) mol

Steps 6, 7, 8, and 9:

Overall Material balances

Element balance or make compound balances

	IN		OUT
C:	50(1.25)(3)	=	$n_{C_2H_4}(2) + n_{CO_2} + 3n_{C_3H_8}$
H:	50(1.25)8	=	$n_{C_2H_4}(4) + n_{H_2O}(2) + n_{C_3H_8}(8)$
O:	100(2)	=	$n_{CO_2}(2) + n_{H_2O} + n_{O_2}(2)$

(continued)



Compound balance on C_3H_8 and O_2

	in	out	gen.	cons.	
C_3H_8 :	50(1.25)	$-n_{\text{C}_3\text{H}_8}$	+0	$-0.40(50)(1.25)$	= 0
	$n_{\text{C}_3\text{H}_8} = 37.5$				
C_2H_4 :	0	$-n_{\text{C}_2\text{H}_4}$	+ 0.40(50)(1.25)	-0	= 0
	$n_{\text{C}_2\text{H}_4} = 25$ and $n_{\text{CO}_2} = 25$				
	$n_{\text{H}_2\text{O}} = 2(25) = 50$				
O_2 :	100	$-n_{\text{O}_2}$	+ 0	$- \frac{0.40(50)(1.25)\text{mol C}_3\text{H}_8}{1\text{ mol C}_3\text{H}_8} \times 2\text{ mol O}_2$	
	$n_{\text{O}_2} = 50\text{ mol}$				

Energy balance

The general energy balance reduces to $Q = \Delta H$

IN

comp.	g mol	T(K)	$\Delta \hat{H}_f^\circ$ (kJ/g mol)	$\Delta \hat{H}_{25}^T$ (kJ/g mol)	ΔH (kJ)
$\text{C}_3\text{H}_8(\text{g})$	62.5	450	-103.85	(15.489-1.771)	-5,633.3
$\text{O}_2(\text{g})$	100	300	0	(0.790-0.732)	5.8
					<u>-5,672.5</u>

OUT

$\text{C}_2\text{H}_4(\text{g})$	25	800	52.233	(34.329-1.054)	2,139.0
$\text{CO}_2(\text{g})$	25	800	-393.51	(23.710-.912)	-9,267.8
$\text{H}_2\text{O}(\text{g})$	50	800	-241.826	(18.823-.837)	-11,192.0
$\text{C}_3\text{H}_8(\text{g})$	37.5	800	-103.85	(61.337-1.771)	-1,660.65
					<u>-19,981.5</u>

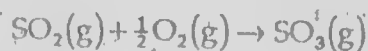
$$Q = (-19,981.5) - (-5,672.5) = -14,309 \text{ kJ/100 g mol}$$

$$\frac{-14,309}{100} \times 62.5 = \boxed{-8,943 \text{ kJ (heat removed)}}$$

5.124

Basis: 1 hr operation

Reference T = 25°C



Use heat capacity equations or enthalpy tables to get ΔH data. System is the converter. Steady state with reaction.

(continued)

Solutions-Chapter-5

In:

Comp.	Mol	Temp °C	Sensible Heat ΔH (J)	ΔH_f° (J)
SO ₂	8.0	400	134,900	8(-296,900) = -2,375,000
O ₂	11.0	400	128,300	0
N ₂	82.8	400	926,500	0
Total			1,189,700	-2,375,000

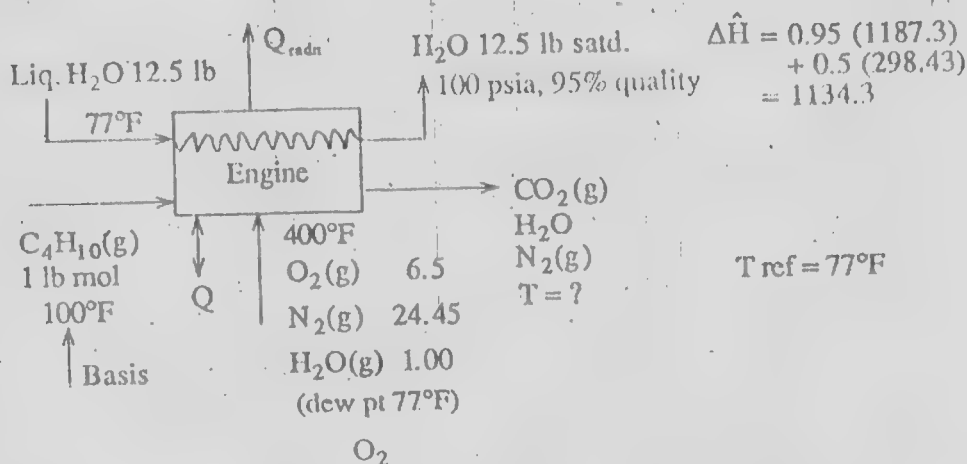
Out:

Comp.	Mol	Temp °C	Sensible Heat ΔH (J)	ΔH_f° (J)
SO ₃	6.4	400	149,200	6.4(-395,180) = -2,539,000
SO ₂	1.6	400	27,000	1.6(-296,900) = -475,000
O ₂	7.8	400	91,000	
N ₂	82.8	400	926,500	
Total			1,193,700	-3,004,000

in kJ:

$$[-3,004 + 1,194] - [-2,375 + 1,190] = -625 \text{ kJ per hour (heat removed).}$$

5.125



You can solve the problem by finding T, or assume T = 1500°F and see if Q is + (then T will be < 1500°F when Q = 0) or Q is - (then T will be > 1500°F when Q = 0)



Material balance (ignore heated H₂O)

(continued)

$$\begin{array}{lcl} \text{IN:} & \text{C}_4\text{H}_{10}(\text{g}) & 1 \text{ lb mol} \\ & \text{air:} & 6.5 \text{ lb mol O}_2 \\ & & \frac{.5}{.21} \cdot 79 \text{ lb mol N}_2 = \frac{24.45}{\text{Total}} \text{ lb mol N}_2 \\ & & \underline{30.95} \end{array}$$

$$\text{H}_2\text{O}(\text{g}) \quad p_{\text{H}_2\text{O}}^* = 0.461 \text{ psia} \quad \frac{p_{\text{H}_2\text{O}}^*}{p_{\text{gas}}} = \frac{0.461}{14.235} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{gas}}} = \frac{n_{\text{H}_2\text{O}}}{30.95}$$

$$p_T = 14.69 \text{ psia}$$

$$p_{\text{gas}} = 14.697 - .461 = 14.235 \quad n_{\text{H}_2\text{O}} = 1.00 \text{ lb mol}$$

OUT:

$$\text{CO}_2: 4 \text{ lb mol}$$

$$\text{N}_2: 24.45 \text{ lb mol}$$

$$\text{H}_2\text{O}: 1.00 + 5 = 6.00 \text{ lb mol}$$

$$Q + \dot{W} = \Delta H = \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

Energy balance

Let system be combustion system

Then Q^* for water being heat is

$$Q^* = \Delta H = 12.5 \text{ lb} [1134.3 - 45.0] = 13,616 \text{ Btu/lb C}_4\text{H}_{10}$$

 Q_{radn} = ignore for the moment -- it is small

$$\text{Enthalpies in} \quad n_i (\Delta \hat{H}_{\text{sensiblc}} + \Delta \hat{H}_f^*) = \Delta \hat{H}_{\text{in}} \left(\frac{\text{Btu}}{\text{lb mol}} \right)$$

$n\text{-C}_4\text{H}_{10}(\text{g})$	$[-124,730 + (1582-1030)]$	1	=	-124,178
$\text{O}_2(\text{g})$	$[0 + (2634-315.1)]$	6.5	=	15,073
$\text{N}_2(\text{g})$	$[0 + (2570-312.2)]$	24.45	=	55,203
$\text{H}_2\text{O}(\text{g})$	$[-241,826 + (3001-360.5)]$	1.00	=	239,186
				-293,087

Enthalpies out (assume 1500°F)

$\text{CO}_2(\text{g})$	$[-393,510 + (16,860-392.2)]$	4	=	-1,508,169
$\text{N}_2(\text{g})$	$[0 + (10,799-312.2)]$	24.45	=	256,402
$\text{H}_2\text{O}(\text{g})$	$[-241,826 + (13,140-360.5)]$	6.00	=	-1,374,279
				-2,626,046

(continued)

$$Q_{\text{net}} + (-13,616)(58) - Q_{\text{radn}} = \Delta H = -2,626,046 - (-293,087)$$

$$Q_{\text{net}} - Q_{\text{radn}} = -1.54 \times 10^6 \text{ Btu/lb mol } C_4H_{10}$$

Temperature > 1500°F

5.126

Higher heating values

	Data Price	Heat of Combustion at 25°C (all negative)
(a) Natural gas	\$2.20/10 ³ ft ³	212.80 k cal/g mol
(b) No. 2 fuel oil	\$0.85/gal	19,450 Btu/lb
(c) Douglas fir	\$95.00/cord	8600 Btu/lb or 22.0 × 10 ⁶ Btu/cord (Perry, 5th ed. p. 9-8)
(d) Coal	\$35.00/ton	~ 11,960 Btu/lb dry

Basis: 10⁶ Btu

$$a. \frac{\$2.20}{10^3 \text{ ft}^3} \left| \frac{359 \text{ ft}^3 \text{ at SC}}{1 \text{ lb mol}} \right| \left| \frac{298 \text{ K}}{278 \text{ K}} \right| \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| \left| \frac{1 \text{ g mol}}{212.8 \text{ k cal}} \right| \left| \frac{1 \text{ k cal}}{10^3 \text{ cal}} \right| \left| \frac{252 \text{ cal}}{1 \text{ Btu}} \right| 10^6 \text{ Btu}$$

$$= \$2.21/10^6 \text{ Btu}$$

$$b. \text{ Sp. gr. oil is } = \frac{141.5}{33+131.5} = 0.86$$

$$\frac{\$0.85}{\text{gal}} \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| \left| \frac{1 \text{ ft}^3}{62.4 \text{ lb H}_2\text{O}} \right| \left| \frac{1}{0.86} \right| \left| \frac{1 \text{ lb}}{19,450 \text{ Btu}} \right| 10^6 \text{ Btu} = \$6.09/10^6 \text{ Btu}$$

c.



A cord is 8 ft long × 4 ft × 4 ft in size. Assume the cord is composed of 6" logs so that there are 8 across and 8 high.

$$\text{Wood area} = (64) \left(\frac{\pi}{4} \right) \left(\frac{1}{2} \right)^2 = 12.57 \text{ ft}^2$$

$$\text{cord area} = (4 \text{ ft}) (4 \text{ ft}) = 16 \text{ ft}^2$$

sp. gr. of yellow pine is about 0.65 (Perry, 5th ed., p. 3-90).

$$\frac{\$95.00}{\text{cord}} \left| \frac{1 \text{ cord}}{128 \text{ ft}^3} \right| \left| \frac{16 \text{ ft}^2 \text{ cord}}{12.57 \text{ ft}^2 \text{ wood}} \right| \left| \frac{\text{ft}^3}{62.416} \right| \left| \frac{1 \text{ lb}}{0.65} \right| \left| \frac{10^6}{8600 \text{ Btu}} \right|$$

$$= \$2.71/10^6 \text{ Btu} (\$4.32 \text{ for the } 22 \times 10^6 \text{ Btu/cord data})$$

$$d. \frac{\$55.00}{\text{ton}} \left| \frac{1 \text{ ton}}{2000 \text{ lb}} \right| \left| \frac{1 \text{ lb}}{11,960 \text{ Btu}} \right| 10^6 \text{ Btu} = \$2.20/10^6 \text{ Btu}$$

(continued)

Solutions-Chapter-5

e. electricity

$$\frac{\$0.032}{(\text{kw})(\text{hr})} \left| \frac{1 (\text{kw})(\text{hr})}{3.413 \times 10^3 \text{ Btu}} \right| 10^6 = \$9.38/10^6 \text{ Btu}$$

Rank	Source of Energy	\$/10 ⁶ Btu
1	Coal (d)	2.20
2	Natural gas (a)	2.21
3	Wood (c)	2.71
4	No.2 fuel oil	6.09
5	Electricity (e)	9.38

5.127 a. Gas Basis 100 g mol Ref. temp. 25°C

Material balances:

Comp.	%=mol	O ₂ reqd.	mol	CO ₂	H ₂ O	1/2
CH ₄	96.0	CH ₄ + 2 O ₂ → CO ₂ + 2 H ₂ O (g)	192	96	192	-
CO ₂	3.0			3		
N ₂	1.0					1
	100.0					
N ₂ entering 192 (72/21) = 722.3						722.3
Total				99	192	722.3

$$Q = \Delta H = \sum \Delta \hat{H}_{\text{prod}} - \sum \Delta \hat{H}_{\text{react}} = 0 \text{ and solve for products}$$

$$\Delta \hat{H}_f^\circ = \begin{matrix} \text{H}_2\text{O} & \text{CO}_2 & \text{CH}_4 \\ (-241.826) & (-393.51) & (-74.84) \end{matrix}$$

In

Comp.	g mol	$\Delta \hat{H}$ (kJ/g mol)	$\Delta \hat{H}_f^\circ$ (kJ/g mol)	ΔH (kJ)
O ₂	192.0	-(.732 - .527)		- 39.36
CH ₄	96.0	-(.879 - .630)	-74.84	-7208.54
CO ₂	3.0	-(.912 - .655)	-393.51	-1181.32
N ₂	1.0	-(.728 - .524)	0	- 0.20
	292.0			-8429.42

Out

Use either the enthalpy tables and trial and error, or calculate the temperature so that $\Delta H_{\text{out}} = -8429.42$:

$$En_i \left[\int_{25^\circ\text{C}}^{T_c} C_{P_i} dT + \Delta \hat{H}_f^\circ \right]$$

(continued)

Solutions-Chapter-5

and solve the polynomial equation obtained by integration via a computer code. The following is trial and error.

Assume $T = 2250 \text{ K}$

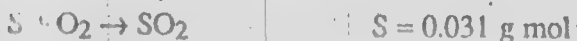
Comp.	g mol	$\Delta \hat{H} \text{ (kJ/g mol)}$	$\Delta \hat{H}_f^\circ \text{ (kJ/g mol)}$	$\Delta H \text{ (kJ)}$
CO ₂	99.0	(107.738 - .912)	-393.51	-28,381.72
H ₂ O	192.0	(85.855 - .837)	-241.83	-30,107.90
N ₂	723.4	(65.981 - .728)	0	47,204.02
				<u>-11,285.60</u>

Assume $T = 2500 \text{ K}$

CO ₂	99.0	(123.176 - .912)	-393.51	-26,853.35
H ₂ O	192.0	(98.867 - .837)	-241.83	-27,608.60
N ₂	723.0	(75.060 - .728)	0	53,742.04
				<u>-720.92</u>

$$= \frac{(-11,285) - (-8429)}{(-11,285) - (-721)} (250) + 2250 = \boxed{2318\text{K}}$$

b. Oil Basis: 100 g oil $\equiv$ 0.438 g mol C₁₆H₃₄ (mol wt = 226.27)



Ignore the ΔH of the C and S.

In:		Out:	
	g mol		g mol
O ₂ req'd	10.75	CO ₂	7.008
N ₂ in	40.36	H ₂ O	7.446
		SO ₂	0.031
		N ₂	40.36

Comp.	g mol	$\Delta \hat{H} \text{ (kJ/g mol)}$	$\Delta \hat{H}_f^\circ \text{ (kJ/g mol)}$	$\Delta H \text{ (kJ)}$
C ₁₆ H ₃₄	0.438	-	?	
S	0.031	-	0	
O ₂	10.75	(.527 - .732)	0	
N ₂	40.36	(.524 - .728)	0	

$\Delta H_{\text{combustion}}$ from Perry (for gaseous products) of the oil is -10,505.6 cal/g.

$$\Delta H_{\text{rxn}}^\circ = \frac{92}{1} \left| \frac{-10,505.6 \text{ cal}}{\text{g}} \right| \frac{4.184 \text{ J}}{1 \text{ cal}} = -4351.59 \text{ kJ}$$

$$\Delta H_{\text{rxn}}^\circ \text{ for S} = \frac{-226.20 \text{ kJ}}{\text{g mol}} \left| \frac{0.031 \text{ g mol}}{1} \right| = -9.20 \text{ kJ} \quad (\text{continued})$$

$$\Delta H_{\text{prod}} = 4350.36 \text{ kJ}$$

Assume $T = 2250 \text{ K}$

Comp.	g mol	$\Delta \hat{H}$ (kJ/g mol)	$\Delta \hat{H}_f^\circ$ (kJ/g mol)	ΔH (kJ)
CO ₂	7.008	(107,738 - 912)	-393.51	
H ₂ O	7.446	(85,855 - 837)	-241.826	
SO ₂	0.031	(105,562 - 984)	-296.90	
N ₂	40.36	(65,981 - 728)	0	

Assume $T = 2500 \text{ K}$

CO ₂	7.008	(123,176 - 912)	-393.51
H ₂ O	7.446	(98,867 - 837)	-241.826
SO ₂	0.031	(119,871 - 984)	-296.90
N ₂	40.36	(75,060 - 728)	0

$$T = 2395 \text{ K}$$

c. Coke Basis: 100 g

In: C = 95 g ash = 5 g
= 7.917 g molC + O₂ → CO₂
O₂ req'd = 7.917 g mol
N₂ = 29.782 g molOut: CO₂ = 7.907 g
N₂ = 29.782 g

In:

 ΔH_{react}

Comp.	g or mol	C_p or ΔH (kJ)	ΔT	ΔH (kJ)	$\Delta \hat{H}_f^\circ$	ΔH
C	7.917	11 (J/(g mol) (K)	-7	-0.6096	0	
ash	5 g	1.15 (J/(g) (°C)	-7	-0.040	?	
O ₂	7.917	(.527 - .732)		-1.623	0	
N ₂	29.782	(.524 - .728)		-6.075	0	
		Total		-8.348		

Out:

Assume $T = 2250 \text{ K}$

Comp.	mol	ΔH (J/g mol)	ΔH (kJ)	$\Delta \hat{H}_f^\circ$	ΔH
CO ₂	7.917	(107,738 - 912)	845.74	-393.51	
N ₂	29.782	(65,981 - 728)	1,943.37	0	
ash	5 g	$C_p \Delta T = 1.15 (527 - 25)$	2.80	?	
		Total	2,791.91		

Solutions-Chapter-5

Assume $T = 2500 \text{ K}$

CO ₂	7.917	(123,176 - 912)	967.96
N ₂	29.782	(75,060 - 728)	2,213.76
ash	5 g	$C_p \Delta T = 1.15 (527 - 298)$	2.80
Total			3,184.52

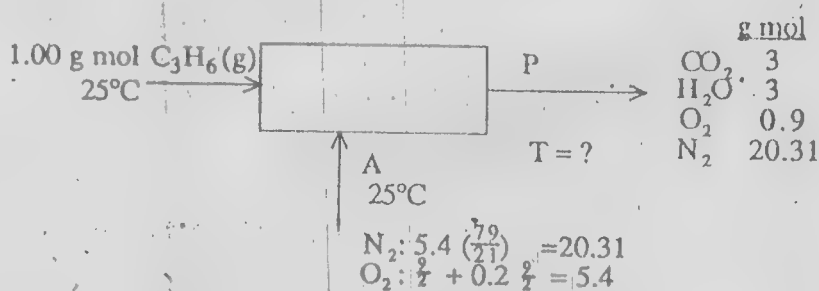
$$T = 2445 \text{ K}$$

The coke gives the highest temperature.

5.128



Basis: 1 g mol C₃H₆ (g)



$$\Delta E = 0 = -\Delta H + Q + W \quad \text{or} \quad \Delta H = \sum \Delta H_{\text{prod}} - \sum \Delta H_{\text{react}} = 0$$

Air in: req'd O₂: 9/2 g mol

xs 20% (2) (9/2) = .9 g mol

5.4 g mol O₂

N₂ in 5.4 (79/21) = 20.31 g mol

Reactants:	g mol	Sensible heat $\Delta \hat{H} (\text{kJ/g mol})$	$\Delta \hat{H}_f^\circ (\text{kJ/g mol})$	$\Delta H (\text{kJ})$
C ₃ H ₆ (g)	1	0	20.41	20.41
O ₂ (g)	5.4	0	0	0
N ₂ (g)	20.31	0	0	0
				20.41

Products: Assume $T = 2000 \text{ K}$

	g mol	$\Delta \hat{H} (\text{kJ/g mol})$	$\Delta \hat{H}_f^\circ (\text{kJ/g mol})$	$\Delta H (\text{kJ})$
CO ₂ (g)	3	(92.466 - 912)	-393.51	-905.87
H ₂ O (g)	3	(73.136 - 837)	-241.826	-508.58
O ₂ (g)	0.9	(59.914 - 732)	0	53.26
N ₂ (g)	20.31	(56.902 - 728)	0	1140.89
				-220.30

(continued)

Solutions-Chapter-5

Assume $T = 2500\text{K}$

$\text{CO}_2(\text{g})$	3	(123.176-912)	-393.51	-813.74
$\text{H}_2\text{O}(\text{g})$	3	(98.867-837)	-241.826	-431.39
$\text{O}_2(\text{g})$	0.9	(79.119-732)	0	70.55
$\text{N}_2(\text{g})$	20.31	(75.060-728)	0	1502.68
				<u>335.11</u>

By linear interpolation $T = 2180\text{K}$

5.129 By making an adiabatic flame temperature calculation (see computer code on disk) for each gas, the values, in order of increasing temperature, are found to be:

CH_4 (3750°F)

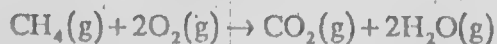
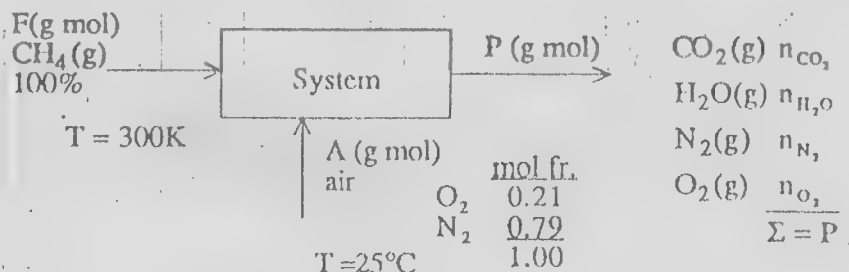
C_2H_6 (3820°F)

C_4H_8 (3870°F)

Equilibrium aspects were not taken into account in the calculations.

5.130 Steps 1, 2, 3, and 4

This is an open system with reaction. The process is in the steady state.



$\Delta \hat{H}_f^\circ (\text{kJ/g mol})$	-74.84	0	-393.51	-241.826
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Step 5 Basis: 1 g mol $\text{CH}_4(\text{g})$

(continued)

Solutions-Chapter-5

Step 4

Calculate the amount of entering air:

O₂ required: 2 g mol

O₂ entering: 2(1.10) = 2.20 g mol

N₂ entering: 2.20 (0.79/0.21) = 8.28 g mol

Steps 5, 6, 7, 8, and 9

Calculate the amount of exit gas

Balances (g mol)	In	=	Out
C	1	=	n_{CO_2}
H	1(4)	=	$n_{\text{H}_2\text{O}}(2)$
O	2.20(2)	=	$n_{\text{O}_2}(2) + n_{\text{H}_2\text{O}} + n_{\text{CO}_2}(2)$
N	8.28	=	n_{N_2}

Summary of moles out:

$n_{\text{CO}_2} = 1$ g mol

$n_{\text{N}_2} = 8.28$ g mol

$n_{\text{H}_2\text{O}} = 2$ g mol

$n_{\text{O}_2} = 0.20$ g mol

The energy balance for an adiabatic process reduces to $\Delta H = 0 =$

$\sum_{\text{products}} n_i \hat{A}H_i - \sum_{\text{reactants}} n_i \hat{A}H_i$. Because the outlet temperature is to be calculated, if we use enthalpy tables for the gases, a trial and error solution is required. If we integrate heat capacity equations, solution of a cubic or quadratic equation in the outlet temperature is required (if truncate C_p equations).

Compound	g mol	T	$\hat{A}H_f^\circ$ (kJ/g mol)	$\hat{A}H_{298}^\circ$ (kJ/g mol)	ΔH (kJ)
Reactants:					
CH ₄ (g)	1.0	300K	-74.84	(0.950-0.879)	-74.77
O ₂ (g)	2.2	25°C	0	0	0
N ₂ (g)	8.28	25°C	0	0	0
					-74.77
Products:					
Assume T = 2000K					
CO ₂ (g)	1.0	2000K	-393.51	(92.446-0.912)	-301.96
H ₂ O(g)	2.0	2000K	-241.826	(73.136-0.837)	-339.05
O ₂ (g)	0.20	2000K	0	(59.914-0.732)	11.84
N ₂ (g)	8.28	2000K	0	(56.902-0.728)	466.24
					-162.93

T = 2000K is too low

(continued)

Assume $T = 2250\text{K}$

$\text{CO}_2(\text{g})$	1.0	2250K	-393.51	(107.738-0.912)	-268.68
$\text{H}_2\text{O}(\text{g})$	2.0	2250K	-241.826	(85.855-0.837)	-313.62
$\text{O}_2(\text{g})$	0.20	2250K	0	(69.454-0.732)	13.74
$\text{N}_2(\text{g})$	8.28	2250K	0	(65.981-0.726)	<u>540.31</u>
					-46.24

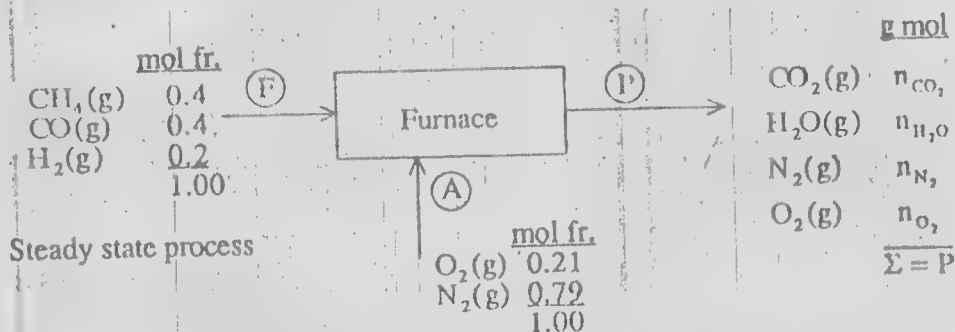
 $T = 2250\text{K}$ is still too lowAssume $T = 2500\text{K}$

$\text{CO}_2(\text{g})$	1.0	2500K	-393.51	(123.176-0.912)	-271.25
$\text{H}_2\text{O}(\text{g})$	2.0	2500K	-241.826	(98.867-0.837)	-287.59
$\text{O}_2(\text{g})$	0.20	2500K	0	(79.119-0.732)	15.68
$\text{H}_2\text{O}(\text{g})$	8.28	2500K	0	(75.060-0.726)	<u>616.96</u>
				Total	73.80

 $T = 2500\text{K}$ is too high Δ linear interpolation gives

$$T = 2250 + \frac{-46.24}{-46.24 - 73.80} (250) = \boxed{2346\text{K}}$$

5.131



Basis: 1 g mol F

Calculation for xs air:

	O_2 reqd		g mol
$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$	0.4(2)	=	0.8
$\text{CO} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}_2$	0.4($\frac{1}{2}$)	=	0.2
$\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$	0.2($\frac{1}{2}$)	=	0.1
xs O ₂ :	1.1(3.0)		3.3
	Total O ₂ in		4.4
N ₂ in:	4.4($\frac{79}{21}$)	=	16.55

Solutions-Chapter-5

Material balance for output (g mol)

CO ₂ : (C balance)	0.4 + 0.4 =	g mol 0.80
H ₂ O: (H ₂ bal)	0.4(2) + 0.2 =	1.0
O ₂ : (O ₂ bal)	0.4($\frac{1}{2}$) + 4.4 - 0.80 - 1.0($\frac{1}{2}$) =	3.3 (the xs)
N ₂		16.55

Energy balance reduces to $Q = \Delta H$ and $Q = 0$ so $\Delta H = 0$

Let $T_{ref} = 25^\circ\text{C}$

Let $T = 1000^\circ\text{C}$

Output	g mol	$\Delta \hat{H}_f^\circ$ (cal/g mol)	$\Delta \hat{H}_{25}^\circ$ (cal/g mol)	$\Delta \hat{H}$ (cal)
CO ₂ (g)	0.8	-94,052	(11,846-217.9)	-65,939
H ₂ O(g)	1.0	-57,798	(9210-200.3)	-48,788
O ₂ (g)	16.55	0	(7482-174)	+120,947
N ₂ (g)	3.3	0	(7916-175)	+25,545
			Total	+31,765

Input (stays same for each output T)

CH ₄ (g)	0.4	-17,889	0	-7,155.6
CO(g)	0.4	-26,416	0	-10,566.4
H ₂ (g)	0.2	0	0	
O ₂ (g)	4.4	0	0	
N ₂ (g)	16.55	0	0	
			Total	-17,722

$$\Delta H = 31,765 - (-17,722) = 49,487 \text{ (too high)}$$

Let $T = 500^\circ\text{C}$

Output				
CO ₂ (g)	0.8	-94,052	(5340-217.9)	-71,144
H ₂ O(g)	1.0	-57,798	(4254-200.3)	-53,744
N ₂ (g)	16.55	0	(3569-174)	+56,187
O ₂ (g)	3.2	0	(3745-175)	+11,781
			Total	-56,920

$$\Delta H = -56,920 - (-17,722) = -39,698 \text{ (too low)}$$

$$1000^\circ\text{C} - \frac{49,487 - 0}{49,487 - (-39,698)}(500) = \boxed{723^\circ\text{C}}$$

5.132

Basis: 1 lb butane

a. $W = -\int F d\ell = -\int_{V_1}^{V_2} p dV$ Assume a batch process. Vaporization is at constant p.

70 kPa = 10 psia. Use the butane chart in the text for

$\hat{V}_2 = 0.65 \text{ ft}^3/\text{lb}$ (Perry indicates ~ 0.62); (or $0.0405 \text{ m}^3/\text{kg}$). from Appendix D,

$$\hat{V}_2 = \frac{1 \text{ ft}^3}{62.4 \text{ lb}} \left| \frac{1}{0.579} \right| = 0.0277 \text{ ft}^3/\text{lb} \quad (\text{or } 0.00173 \text{ m}^3/\text{kg})$$

Basis: 1 kg butane

$$W = -p\Delta\hat{V} = \frac{70 \times 10^3 \text{ N}}{\text{m}^2} \left| \frac{(0.65 - 0.0277) \text{ ft}^3}{\text{lb}} \right| \left| \frac{1 \text{ m}^3}{3.28 \text{ ft}} \right| \left| \frac{1 \text{ lb}}{0.454 \text{ kg}} \right| =$$

$$\boxed{-2.72 \text{ kJ/kg or } 1.17 \text{ Btu/lb}}$$

b. The energy balance cannot be used to calculate W Because Q is not known. If Q is known,

$$\Delta\hat{E} = \hat{Q} + \hat{W} \quad \text{so} \quad -\hat{W} = \hat{Q} - \Delta\hat{E} = \hat{Q} - (\Delta\hat{H} - p\Delta\hat{V})$$

5.133

Basis: 1 lb mole H_2O

Process: reversible batch, no reaction. System: vessel of water.

$$E_2 - E_1 = Q + W - \Delta H - \Delta K - \Delta P \quad \Delta K = 0 \quad \Delta P = 0$$

This equation will not lead to a single unknown, W, from the data given. Because the process is reversible (since the temperature and pressure are constant)

$W_{\text{rev}} = -\int p dV = -p\Delta V$. Work is done against the atmosphere.

$$\Delta\hat{V} \text{ from Steam Tables} = (26.81 - 0.0167) \text{ ft}^3/\text{lb}$$

$$W = - \frac{14.7 \text{ lb}_f}{\text{in}^2} \left| \frac{144 \text{ in}^2}{1 \text{ ft}^2} \right| \left| \frac{(26.83 - 0.0167) \text{ ft}^3}{\text{lb}} \right| \left| \frac{1 \text{ Btu}}{778 \text{ (ft) (lb}_f\text{)}} \right| \left| \frac{18 \text{ lb}}{1 \text{ lb mol}} \right|$$

$$= \boxed{-1313 \text{ Btu/lb mol}}$$

Solutions-Chapter-5

5.134

Basis: 1 kg steam

Paths are not shown but the data are:

State 1	State 2	State 3	State 4	State 5	Units
540	540	199	143	425	T(°C)
2700	700	400	400	2700	p(kPa)
0.1361	0.5339	0.5339	0.4625	0.1161	$\hat{V}(\text{m}^3/\text{kg})$
3542	3558	2862	2733	3285	$\Delta\hat{H}(\text{kJ/kg})$

Energy balance: $Q + W = \Delta U$ for a batch process

$$\text{Reversible work: } W_{\text{rev}} = - \int_{\hat{V}_1}^{\hat{V}_2} p d\hat{V}$$

State 1 → State 2 at constant T = 540°C

$$\Delta\hat{H} = 3558 - 3542 = 16 \text{ kJ/kg}$$

$$\Delta\hat{U} = \Delta\hat{H} - \Delta(p\hat{V}) = 16 - [(700)(0.5339) - (2700)(0.1361)] = \boxed{9.7 \text{ kJ/kg}}$$

W_{rev} can be calculated by selecting $(p, \hat{V})$ pairs along an isotherm and integrating the area under a plot of p vs $\hat{V}$. Q then can be calculated from $Q = \Delta U - W$.

State 2 → State 3 at constant V

$$\Delta\hat{H} = 2862 - 3558 = -696 \text{ kJ/kg}$$

$$\Delta\hat{U} = -696 - [(400)(0.5339) - 700(0.5339)] = -535.8 \text{ kJ/kg}$$

$$W_{\text{rev}} = 0 \text{ as } \Delta V = 0$$

$$Q = \Delta U = \boxed{-535.8 \text{ kJ/kg}}$$

State 3 → State 4 at constant p

$$\Delta\hat{H} = 2733 - 2862 = -129 \text{ kJ/kg}$$

$$\Delta\hat{U} = -129 - [(400)(0.4625) - (400)(0.5339)] = -100 \text{ kJ/kg}$$

(continued)

Solutions-Chapter-5

$$W_{\text{rev}} = -p\Delta V = 40 (0.4625 - 0.5339) = 28.6 \text{ kJ/kg}$$

$$Q = \Delta U - W = -100 - (28.6) = \boxed{-129 \text{ kJ/kg}}$$

State 4 $\rightarrow$ State 5 with $Q = 0$

$$\Delta \hat{H} = 3285 - 2733 = 552 \text{ kJ/kg}$$

$$\Delta \hat{U} = 552 - [(2700)(0.1161) - (400)(0.4625)] = 423.5 \text{ kJ/kg}$$

$$Q = 0$$

$$-W = Q - \Delta U = -423.5 \text{ kJ/kg} \quad \text{or } W = \boxed{423.5 \text{ kJ/kg}}$$

State 5 $\rightarrow$ State 1

$$\Delta \hat{H} = 3542 - 3285 = 257 \text{ kJ/kg}$$

$$\Delta \hat{U} = 257 - [(2700)(0.1361) - (2700)(.1161)] = 203 \text{ kJ/kg}$$

$$Q = ?$$

$$W_{\text{rev}} = ? \text{ (cannot be calculated because path is unknown)}$$

Check

$$\text{Is } \sum \Delta \hat{H} = 0, \text{ yes; Is } \sum \Delta U = 0, \sum \Delta U = 0.43 \text{ which is close enough}$$

5.135

Basis: 1 lb mol H_2O

Initial State

Water at 212°F
and 1 atm (enthalpy = ΔH_1)

Final State

Saturated steam at 212°F
and 1 atm (enthalpy = ΔH_2)

- a. Steady state open (flow) process: flow in a pipeline, negligible kinetic and potential energy changes. No work is done by the system or on the system so that $W = 0$, and,

$$\Delta H_2 - \Delta H_1 = \Delta H = Q + W = 0$$

$$\boxed{W = 0}$$

(continued)

Solutions-Chapter-5

b. Closed (non-flow) process: The basic equation is:

$$\Delta U_2 - \Delta U_1 = \Delta U = Q + W = Q - \Delta(pV)$$

Because the work done is only a volume expansion

$$W = -\int_{V_1}^{V_2} p dV = -p\Delta V = -(pV_2 - pV_1)$$

Obtain V_1, V_2 from steam tables

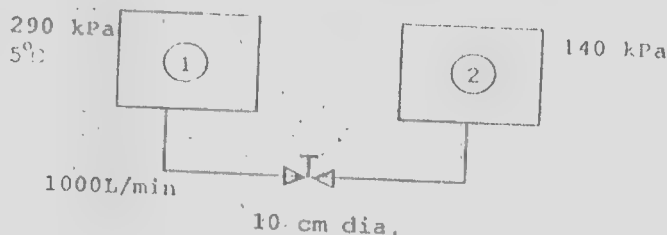
$$W = -p\left(\frac{\text{lb}_f}{\text{ft}^2}\right)(V_2 - V_1)\text{ft}^3 = -(14.7)(144)(26.799 - 0.016719)$$

$$= -56.677 \frac{(\text{ft})(\text{lb}_f)}{\text{lb steam}} = -72.85 \frac{\text{Btu}}{\text{lb}} \quad 1,312 \frac{\text{Btu}}{\text{lb mol}}$$

Work is done against the atmosphere.

5.136

$$\hat{V} = 10^{-3} \text{ m}^3/\text{kg}$$



Basis: 1 min

$$\Delta P + \Delta K + \int_{p_1}^{p_2} \hat{V} dp - W + E_v = 0 \quad \text{used to calculate } E_v \quad \Delta P = \Delta K = W = 0$$

$$E_v = \hat{V} \Delta p = \frac{10^{-3} \text{ m}^3}{\text{kg}} \left| \frac{(290 - 140) 10^3 \text{ N}}{\text{m}^2} \right| \frac{1 \text{ J}}{(\text{N})(\text{m})} = \frac{150 \text{ J}}{\text{kg}}$$

$$\text{a. } \frac{150 \text{ J}}{\text{kg}} \left| \frac{10^3 \text{ L}}{\text{min}} \right| \left| \frac{10^3 \text{ cm}^3}{1 \text{ L}} \right| \left| \frac{1 \text{ m}}{100 \text{ cm}} \right|^3 \frac{\text{kg}}{10^{-3} \text{ m}^3} = \boxed{1.50 \times 10^5 \frac{\text{J}}{\text{min}}}$$

(continued)

$$\Delta \hat{E} = -\Delta [m(\hat{H} + \hat{P} + \hat{K})] + Q + W \quad \text{used to calculate } \Delta T \quad \Delta \hat{E} = \Delta \hat{P} = \Delta \hat{K}$$

$$\Delta \hat{H} = 0 \quad \text{or} \quad \Delta \hat{H}_{\text{out}} - \Delta \hat{H}_{\text{in}} = 0 \quad = Q = W = 0$$

liquid

at 5°C, 290 kPa

 $\Delta \hat{H} = 20.8$ at 140 kPa

$$\Delta \hat{H} = 20.8$$

$$0 = \Delta \hat{H} = \int C_p dT + \int \left(\frac{\partial \hat{H}}{\partial p} \right)_T dp$$

But the second term for a liquid is approximately zero, hence $\Delta T \equiv 0$

5.137

Process: flow, steady state

System: feed water pump

$$\Delta(\hat{K} + \hat{P}) + \int \hat{V} dp - \hat{W}_{\text{rev}} + \hat{E}_v = 0$$

Application of the general equation for the conservation of energy is not too useful since it reduces to, $Q + W = \Delta H$. By assuming a reversible process and applying the given efficiency factor, one obtains the work per time done on the system.

$$W_{\text{rev}} = \int_{p_1}^{p_2} \hat{V} dp$$

If $\hat{V}$ is constant, $W_{\text{rev}} = + \hat{V} \Delta p$.

$$p_2 = 500$$

psia

$$p_1 = 0.9$$

Basis: 100 gal/min

$$\frac{100 \text{ gal}}{\text{min}} \left| \frac{1 \text{ (ft)}^3}{7.48 \text{ gal}} \right| \left| \frac{(500 - 0.9) \text{ (lb}_p\text{)}}{\text{(in)}^2} \right| \left| \frac{144 \text{ (in)}^2}{\text{(ft)}^2} \right| \left| \frac{1 \text{ min}}{60 \text{ sec}} \right| \left| \frac{1 \text{ (hp)}}{550 \text{ (ft) (lb}_p\text{)}} \right| \left| \frac{0.40}{\text{sec}} \right| = \boxed{72.8 \text{ hp}}$$

Solutions-Chapter-5

5.138

Mechanical energy balance:

$$\Delta(\hat{K} + \hat{P}) + \int_{p_1}^{p_2} \hat{V} dp - \hat{W} + \hat{E}_v = 0$$

The minimum work is the reversible work so $\hat{E}_v = 0$. Then

$$\int_{p_1}^{p_2} \hat{V} dp \approx \hat{V} \Delta p$$

because the fluid is incompressible, but $\Delta p = 0$. Thus the mechanical energy balance reduces to

$$W_{rev} = \Delta[(\hat{K} + \hat{P})m]$$

If $\dot{M}$ is the mass/time then, $\dot{W}$ = work/time = power

$$\dot{W} = (\hat{K}_4 + \hat{P}_4) \dot{m}_4 + (\hat{K}_2 + \hat{P}_2) \dot{m}_2 - (\hat{K}_1 + \hat{P}_1) \dot{m}_1$$

where the subscripts refer to the floors.

Basis: flows of water as shown in Figure in text (i.e., 1 min)

Take the first floor as the datum; $\hat{K} = \frac{1}{2} v^2$, $\hat{P} = gh$

$$\hat{P}_1 = 0$$

$$\hat{K}_1 = \frac{1}{2} \left(\frac{60}{60} \right)^2 = 0.5 \text{ ft}^2/\text{s}^2$$

$$\hat{P}_2 = \frac{32.2 \text{ ft}}{\text{s}^2} \left| \frac{30 \text{ ft}}{\text{s}^2} \right| = 965 \frac{\text{ft}^2}{\text{s}^2}$$

$$\hat{K}_2 = \frac{1}{2} \left(\frac{600}{60} \right)^2 = 50.0 \text{ ft}^2/\text{s}^2$$

$$\hat{P}_4 = \frac{32.2 \text{ ft}}{\text{s}^2} \left| \frac{60 \text{ ft}}{\text{s}^2} \right| = 1930 \frac{\text{ft}^2}{\text{s}^2}$$

$$\hat{K}_4 = \frac{1}{2} \left(\frac{1200}{60} \right)^2 = 200.0 \text{ ft}^2/\text{s}^2$$

$$\dot{m}_1 = \frac{500 \text{ gal}}{\text{min}} \left| \frac{0.1337 \text{ ft}^3}{1 \text{ gal}} \right| \left| \frac{62.4 \text{ lb}_m}{1 \text{ ft}^3} \right| \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = 69.6 \text{ lb}_m/\text{s}$$

$$\dot{m}_2 = \frac{200 \text{ gal}}{\text{min}} \left| \frac{0.1337 \text{ ft}^3}{1 \text{ gal}} \right| \left| \frac{62.4 \text{ lb}_m}{1 \text{ ft}^3} \right| \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = 27.5 \text{ lb}_m/\text{s}$$

(continued)

Solutions-Chapter-5

$$\dot{m}_3 = \frac{300 \text{ gal}}{1 \text{ gal}} \left| \frac{0.1337 \text{ ft}^3}{1 \text{ ft}^3} \right| \left| \frac{62.4 \text{ lb}_m}{1 \text{ ft}^3} \right| \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = 41.7 \text{ lb}_m/\text{s}$$

$$\dot{W} = [(200) + 1930) (41.7) + (50 + 96.5) (27.8) - (0.5 + 0)(69.6)]$$

$$\times \frac{(\text{lb}_m) (\text{ft}^2)}{(\text{s}) (\text{s}^2)} = 89,000 + 28,200 - 34.8 = 117,170 \frac{(\text{lb}_m) (\text{ft}^2)}{(\text{s}) (\text{s}^2)}$$

$$\dot{W} = \frac{117,170 \frac{(\text{lb}_m) (\text{ft}^2)}{(\text{s}) (\text{s}^2)}}{32 \frac{(\text{lb}_m) (\text{ft})}{(\text{lb}_f) (\text{s}^2)}} \left| \frac{1}{550 (\text{lb}_f) (\text{ft}/\text{s})} \right| = \boxed{6.62 \text{ hp}}$$

5.139

Process: flow

System: pump

Basis: 1 kg

Use the steady state mechanical energy balance.

$$\Delta (\hat{K} + \hat{P}) + \int_{p_1}^{p_2} \hat{V} dp - \hat{W} + \hat{E}_v = 0$$

a. $\Delta \hat{K} = 0$ Approximately

$$\Delta \hat{P} = mgh = \frac{1 \text{ kg}}{1 \text{ (kg)}} \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{10 \text{ m}}{1 \text{ (m)}} \right| \left| \frac{1 \text{ J (s}^2\text{)}}{1 \text{ (kg) (m}^2\text{)}} \right| = 98.0 \text{ J}$$

$$\int_{p_1}^{p_2} \hat{V} dp = \hat{V} \Delta p \text{ because } \hat{V} \text{ is essentially constant at } 10^{-3} \text{ m}^3/\text{kg}$$

$$= \frac{10^{-3} \text{ m}^3}{\text{kg}} \left| \frac{(1150 - 101.3) \text{ kN}}{\text{m}^2} \right| \left| \frac{1 \text{ J}}{1 \text{ (N) (m)}} \right| = 1050 \text{ J/kg}$$

$$\hat{E}_v = 60.0 \text{ J/kg}$$

$$\hat{W}_{\text{ideal}} = 98.0 + 1050 + 60.0 = 1208 \text{ J/kg}$$

$$\text{Actual work required} = \frac{1208}{0.70} = \boxed{1726 \text{ J/kg}}$$

(continued)

Solutions-Chapter-5

Basis: 1 min

$$b. \frac{1726 \text{ J}}{\text{kg}} \left| \frac{0.40 \text{ m}^3}{\text{min}} \right| \frac{10^3}{\text{m}^3} = \boxed{6.903 \times 10^5 \text{ J/min}}$$

5.140 LHV = 49,100 kJ/kg

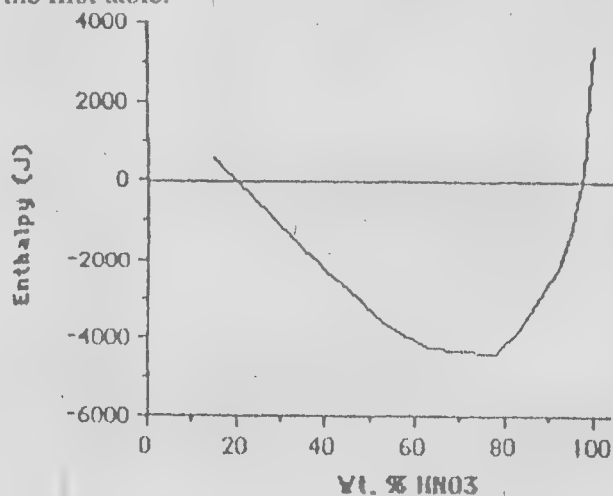
enthalpy = 8790 kJ/kg

$$\text{efficiency} = 100 - 2 - \frac{8790}{49,100} 100 = 80\%$$

5.141 a.

$n_{\text{H}_2\text{O}}$ (moles)	ΔH (J)	moles of sol'n	$\Delta H/\text{mol sol'n}$ (J/g mol sol'n)
0.0	3,375	1.0	3,375
0.1	230	1.1	210
0.2	-1,660	1.2	-1,385
0.3	-2,920	1.3	-2,245
0.5	-3,980	1.5	-2,655
0.67	-6,150	1.67	-3,680
1.0	-8,830	2.0	-4,415
1.5	-10,735	2.5	-4,295
2.0	-12,865	3.0	-4,290
3.0	-14,610	4.0	-3,650
4.0	-14,465	5.0	-2,895
5.0	-14,320	6.0	-2,385
10.0	-6,915	11.0	-630
20.0	-12,705	21.0	605

Plot the enthalpy per mole of solution from the table above as a function of the wt. % HNO_3 from the first table.



(continued)

Solutions-Chapter-5

b. 4 moles H_2O to 4 moles HNO_3 is a 50 mole % solution of acid

$$\begin{array}{ccc} 33 \text{ mole \%} & + & 60 \text{ mole \%} \rightarrow 50 \text{ mole \%} \\ \text{A} & & \text{B} \quad \quad \text{F} \end{array}$$

Basis: 8 mol final solution (F)

Overall balance: $A + B = F = 8$

HNO_3 balance: $0.333 A + 0.60 B = 8 (0.50)$

$$0.333 A + 0.60 (8 - A) = 4$$

Solving: $A = 3 \text{ mol}$ (1 mol HNO_3 , 2 mol H_2O)

$\frac{\text{g mol H}_2\text{O}}{\text{g mol HNO}_3}$	$\text{g H}_2\text{O}$	g HNO_3	g Total	$\text{Wt\% HNO}_3$	$-\Delta H_{\text{soln}}$ at 25°C (J/g mol HNO_3)
0.0	0.0	63.0	63.0	100.0	0
0.1	1.8	63.0	64.8	97.2	3,350
0.2	3.6	63.0	66.6	94.6	5,440
0.3	5.4	63.0	72.0	87.5	8,370
0.67	12.1	63.0	75.1	83.9	10,880
1.0	18.0	63.0	90.0	70.0	17,150
2.0	36.0	63.0	99.0	63.6	20,290
3.0	54.0	63.0	117.0	53.8	24,060
4.0	72.0	63.0	135.0	46.7	25,940
5.0	90.0	63.0	153.0	41.2	27,820
10.0	180.0	63.0	243.0	25.9	30,540
20.0	360.0	63.0	423.0	14.9	31,170

Reference temperature for H_2O and $\text{HNO}_3 = 0^\circ\text{C}$

Solution temperature = 27°C

C_p for $\text{H}_2\text{O} = 75 \text{ J/(g mol)} (^\circ\text{C})$
mol) ($^\circ\text{C}$)

C_p for $\text{HNO}_3 = 125 \text{ J/(g$

$$\Delta H = n_{\text{H}_2\text{O}} \int_0^{27} C_{p, \text{H}_2\text{O}} dT + n_{\text{HNO}_3} \int_0^{27} C_{p, \text{HNO}_3} dT + n_{\text{HNO}_3} (\Delta H_{\text{soln}} \text{ at } 27^\circ\text{C})$$

$C_{p, \text{H}_2\text{O}}$, C_{p, HNO_3} , and n_{HNO_3} are constant at $75 \text{ J/(g mol)} (^\circ\text{C})$, $125 \text{ J/(g mol)} (^\circ\text{C})$, and 1 mol, respectively; therefore

$$\Delta H = n_{\text{H}_2\text{O}} [75 \text{ J/(g mol)} (^\circ\text{C})] (27^\circ\text{C}) + (1 \text{ g mol}) [125 \text{ J/(g mol)} (^\circ\text{C})] (27^\circ\text{C}) + \Delta H_{\text{soln}}$$

(continued)

Solutions-Chapter-5

$$\Delta H = (2025 \text{ J/g mol}) n_{\text{H}_2\text{O}} + 3375 \text{ J} + \Delta H_{\text{sol'n}}$$

For example, for 0.5 g mol H_2O /g mol HNO_3 there are 0.5 g moles H_2O

$$\Delta H = (2025 \text{ J/g mol}) (0.5 \text{ g mol}) + 3375 \text{ J} + -8,370 \text{ J}$$

$$\Delta H = -3980 \text{ J}$$

The problem asks for the enthalpy per mole of solution, so there are 1.5 total moles.

$$\frac{-3980 \text{ J}}{1.5 \text{ mol sol'n}} = -2655 \text{ J/mol sol'n}$$

$$B = 5 \text{ mol (3 mol HNO}_3, 2 \text{ mol H}_2\text{O)}$$

$$Q = \Delta H = \Delta H_F - (\Delta H_A + \Delta H_B)$$

$$A: \text{ ratio is 2 mol H}_2\text{O/mol HNO}_3 = -20,290 \text{ J/g mol HNO}_3$$

$$B: \text{ ratio is 0.67 mol H}_2\text{O/mol HNO}_3 = -10,880 \text{ J/g mol HNO}_3$$

$$F: \text{ ratio is 1 mol H}_2\text{O/mol HNO}_3 = -14,230 \text{ J/g mol HNO}_3$$

$$Q = (-14,230 \text{ J/g mol HNO}_3) (4 \text{ g mol HNO}_3) - [(-20,290 \text{ J/g mol HNO}_3)$$

$$(1 \text{ g mol HNO}_3) + (-10,880 \text{ J/g mol HNO}_3) (3 \text{ g mol HNO}_3)]$$

$$Q = -3,390 \text{ J}$$

5.142

$$Q = \Delta H^\circ = \Delta H^\circ_{20\% \text{ sol'n}} - \Delta H_{\text{CaCl}_2}$$

a. Conversion of 20 wt % to moles:

Basis: 100 g solution

$$\frac{20 \text{ g CaCl}_2}{100 \text{ g solution}} \times \frac{1 \text{ g mol CaCl}_2}{111 \text{ g CaCl}_2} = 0.18 \text{ g mol CaCl}_2$$

$$\frac{80 \text{ g H}_2\text{O}}{100 \text{ g solution}} \times \frac{1 \text{ g mol H}_2\text{O}}{18 \text{ g H}_2\text{O}} = 4.44 \text{ g mol H}_2\text{O}$$

$$(4.44/0.18) = 24.7 \text{ g mol H}_2\text{O/g mol CaCl}_2$$

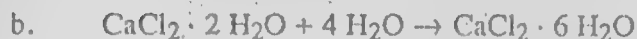
(continued)

Solutions-Chapter-5

$$\Delta H^\circ = \left(\frac{-208.3 \text{ kcal}}{\text{g mol CaCl}_2} \right) \left(\frac{1 \text{ g mol CaCl}_2}{1 \text{ g mol CaCl}_2} \right) - \left(\frac{-190.0 \text{ kcal}}{\text{g mol CaCl}_2} \right) \left(\frac{1 \text{ g mol CaCl}_2}{1 \text{ g mol CaCl}_2} \right) = -18.3 \text{ kcal}$$

Basis: 1 lb mol CaCl₂

$$Q = \Delta H^\circ = \frac{-18,300 \text{ cal}}{\text{g mol}} \left(\frac{454 \text{ g mol}}{\text{lb mol}} \right) \left(\frac{1 \text{ Btu}}{252 \text{ cal}} \right) = \boxed{-33,000 \frac{\text{Btu}}{\text{lb mol}}}$$



$$\Delta H_{\text{hyd}} = (-623.15) - (-333.5) = \boxed{-289.5 \frac{\text{kcal}}{\text{g mol CaCl}_2}}$$

c. A 5% sol'n contains: $(5.28/0.045) = 117.2 \text{ g mol H}_2\text{O/g mol CaCl}_2$

By linear interpolation: $\Delta H = -209.10 \text{ kcal/g mol CaCl}_2$

$$\Delta H^\circ = (-209.10) - (-208.3) = -0.8 \text{ kcal/g mol CaCl}_2$$

$$Q = \Delta H^\circ = (-800) (1.8) = \boxed{1440 \text{ Btu/lb mol CaCl}_2}$$

5.143

Basis: 100 g NH₄OH - H₂O mixture

$$\text{g mol NH}_4\text{OH} = \frac{15 \text{ g}}{35 \text{ g}} = 0.429$$

$$\text{g mol H}_2\text{O} = \frac{85 \text{ g}}{18 \text{ g}} = 4.72$$

	<u>g mol</u>	<u>g</u>	<u>Mass %</u>
NH ₃	0.429	7.29	7.3
H ₂ O	0.429 + 4.72 = 5.149	<u>92.68</u>	<u>92.7</u>
		99.97	100.0

Heat of solution at infinite dilution = -34,600 J/g mol NH₃

Heat of solution (7.3% NH₃) = -34,210 J/g mol NH₃

$$\text{g mol H}_2\text{SO}_4 \text{ req'd} = 1/2 (0.429) = 0.2145$$

$$\text{g mol H}_2\text{O} = 75/25 (0.2145) = 0.6435$$

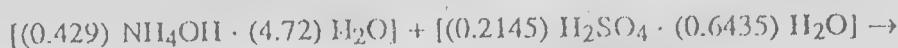
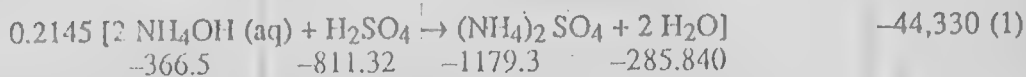
	<u>g mol</u>	<u>g</u>	<u>Mass %</u>
H ₂ SO ₄	0.2145	21.02	64.4
H ₂ O	0.6435	<u>11.60</u>	<u>35.6</u>
		32.62	100.0

(continued)

Solutions Chapter 5

Heat of mixing = -262 J/g

$\Delta H(J)$



Calculations for above work:

$$\text{Rxn 1: } \Delta H_{\text{rxn}} = \sum \Delta H^\circ_{\text{f, prod}} - \sum \Delta H^\circ_{\text{f, react}}$$

$$= [-1179.3 + 2 (-285.84)] - [2 (-366.5) + (-811.32)] (0.2145 \text{ g mol})$$

$$= -44.33 \text{ kJ} = -44,330 \text{ J}$$

$$\text{Rxn 2: } \Delta H_{\text{sol'n}} = \frac{-34,210 \text{ J}}{\text{g mol NH}_3} \left| \frac{0.429 \text{ g mol NH}_3}{\text{g mol NH}_3} \right| = -14,680 \text{ J}$$

$$\Delta H_{\text{dissoln}} = +14,680 \text{ J}$$

$$\text{Rxn 3: } \Delta H_{\text{sol'n}} = \frac{-34,600 \text{ J}}{\text{g mol NH}_3} \left| \frac{0.429 \text{ g mol NH}_3}{\text{g mol NH}_3} \right| = -14,840 \text{ J}$$

$$\text{Rxn 4: } \Delta H_{\text{sol'n}} = \frac{-262 \text{ J}}{\text{g H}_2\text{SO}_4 \text{ sol'n}} \left| \frac{32.62 \text{ g sol'n}}{\text{g H}_2\text{SO}_4 \text{ sol'n}} \right| = -8,550 \text{ J}$$

$$\text{Rxn 5: Assumed } \Delta H_{\text{sol'n}} = 0$$

5.144

Heat of solution data have been taken from *NBS Circular 500*.

(a)

Basis: 17 lb of NH_3 = 1 lb.mol of NH_3

Reference temperature = 77°F = 25°C

To convert from kilocalories per gram mole to British thermal units per pound mole, multiply by 1800.

Description	State	$-\Delta\hat{H}_f^\circ$ (kcal/g mol)	$-\Delta\hat{H}_f^\circ$ (Btu/lb mol)	$-\Delta\hat{H}_{\text{soln}}^\circ$ (Btu/lb mol)	Weight % HN_3
OH_2O	g	11.04	19,900	8,500†	100
$1\text{H}_2\text{O}$	aq	18.1	32,600	12,700	48.5
$2\text{H}_2\text{O}$	aq	18.7	33,600	13,700	32.0
$3\text{H}_2\text{O}$	aq	18.87	34,000	14,100	23.9
$4\text{H}_2\text{O}$	aq	18.99	34,200	14,300	19.1
$5\text{H}_2\text{O}$	aq	19.07	34,350	14,450	15.9
$10\text{H}_2\text{O}$	aq	19.23	34,600	14,700	8.63
$20\text{H}_2\text{O}$	aq	19.27	34,700	14,800	4.51
$30\text{H}_2\text{O}$	aq	19.28	34,700	14,800	3.05
$40\text{H}_2\text{O}$	aq	19.28	34,700	14,800	2.30
$50\text{H}_2\text{O}$	aq	19.29	34,750	14,850	1.85
$100\text{H}_2\text{O}$	aq	19.30	34,750	14,850	0.94
$200\text{H}_2\text{O}$	aq	19.32	34,800	14,900	0.47
$\infty\text{H}_2\text{O}$	aq	19.32	34,800	14,900	0.0

† Represents latent heat of condensation

Standard heats of solution have been calculated from the cumulative data as follows:

$$\Delta\hat{H}_{\text{soln}}^\circ = \Delta\hat{H}_f^\circ - \Delta\hat{H}_{\text{gas}}^\circ$$

For example, for $\text{NH}_3 \cdot 1\text{H}_2\text{O}$:

$$\Delta\hat{H}_{\text{soln}}^\circ = -32,600 - (-19,900)$$

$$= -12,700 \text{ Btu/lb mol } \text{NH}_3$$

Weight percents have been computed as follows:

$$\text{wt. \% } \text{NH}_3 = \frac{1\text{b } \text{NH}_3(100)}{1\text{b } \text{H}_2\text{O} + 1\text{b } \text{NH}_3}$$

$$\text{wt \% } \text{NH}_3 \text{ for } 1\text{H}_2\text{O} = \frac{17(100)}{18(1) + 17} = 48.5\%$$

The heat of solution values shown in Fig. are equivalent to the cooling duty required.

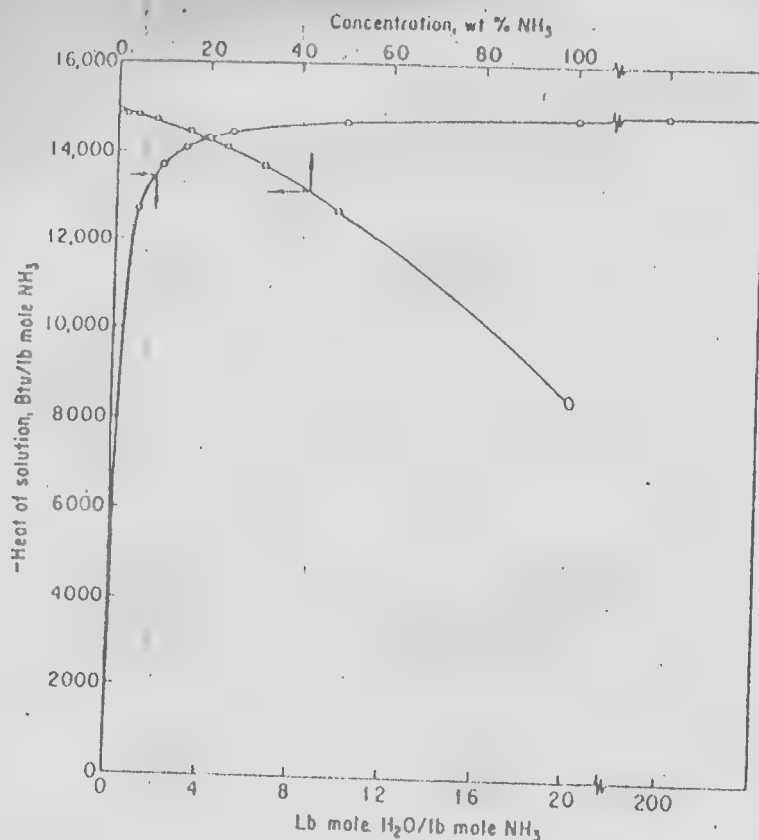


Fig. 5.1

(c) This part of the problem requires that a new basis be selected, 100 gal of solution. Additional data concerning densities of NH_4OH are shown in the table below. Sample calculations are as follows:

$$\text{density (lb/100 gal)} = \frac{(\text{sp gr soln})(62.4 \text{ lb/ft}^3)(1.003)(100)}{7.48 \text{ gal/ft}^3}$$

Note: 1.003 is the specific gravity of water at 77°F.

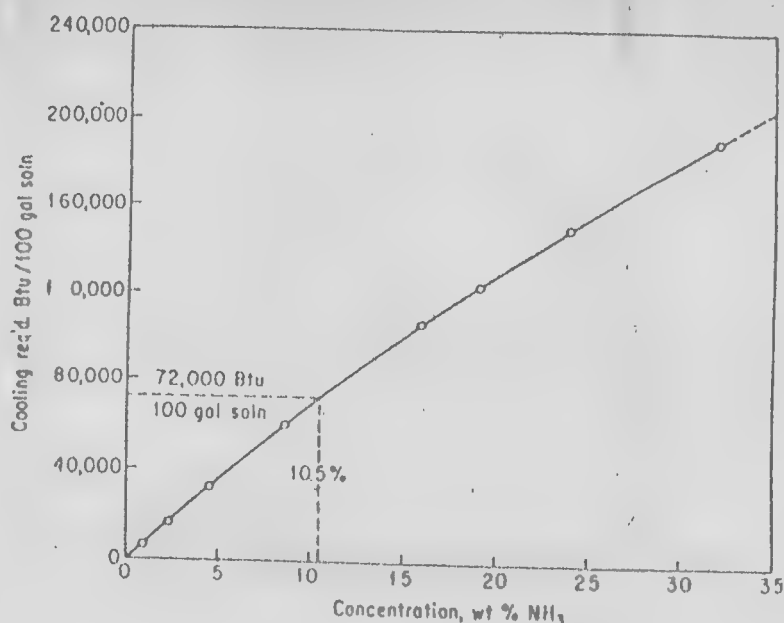
$$\text{density at 32.0\% NH}_3 = \frac{0.889(62.4)(1.003)(100)}{7.48} = 741 \text{ lb/100 gal}$$

$$\left. \begin{array}{l} \text{cooling req'd} \\ \text{Btu/100 gal} \end{array} \right\} = \left(\frac{\text{lb mol NH}_3}{100 \text{ gal}} \right) \left(-\Delta H_{\text{soln}}^{\circ} \frac{\text{Btu}}{\text{lb mol NH}_3} \right)$$

$$\left. \begin{array}{l} \text{cooling req'd} \\ \text{for 100 gal} \\ \text{32.0\% NH}_3 \text{ soln} \end{array} \right\} = 13.94(13,700) = 191,000 \text{ Btu/100 gal soln.}$$

These data are portrayed in Fig.

Solutions-Chapter-5



Basis: 100 gal of solution at concentrations and densities shown

% NH ₃	Sp gr* at 4°C	Density (lb/100 gal)	lb NH ₃ 100 gal	lb mol NH ₃ 100 gal	$-\Delta H_{soln}$ (Btu lb mol NH ₃)	Cooling Req'd per 100 gal (Btu)
32.0	0.889	741	237	13.94	13,700	191,000
23.9	0.914	761	182	10.70	14,100	151,000
19.1	0.929	774	148	8.70	14,300	124,000
15.9	0.940	784	124.7	7.32	14,450	106,000
8.63	0.965	805	69.4	4.08	14,700	60,000
4.51	0.981	819	37.0	2.18	14,800	32,200
3.05	0.986					
2.30	0.990	826	19.0	1.12	14,800	16,600
1.85	0.992					
0.94	0.995	830	7.8	0.46	14,850	6,800
0.47	0.998					
0.0	1.000	834	0	0	14,900	0

*SOURCE: N. A. Lange, *Handbook of Chemistry*, 8th ed., Handbook Publishers, Sandusky, Ohio, 1958.

(c) Basis: 100 gal of solution at 10.5% NH₃

$$\Delta E = \Delta U = mC_p \Delta T \approx mC_p \Delta T = 72,000 \text{ Btu/100 gal}$$

$$\text{sp gr soln} = 0.955$$

$$m = \frac{0.955(6.24)(1.003)(100)}{7.48} = 800 \text{ lb}$$

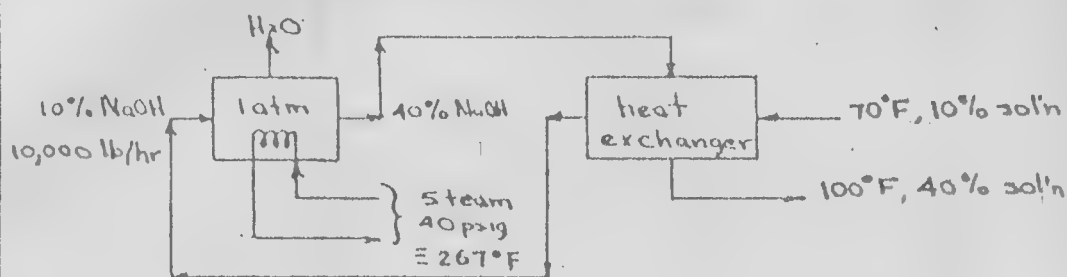
$$C_p \text{ 10.5\% NH}_3 \text{ soln} = 4.261 \text{ J/(g)(}^\circ\text{C)}$$

$$= 1.02 \text{ Btu/(lb)(}^\circ\text{F)}$$

$$\Delta T = \frac{\Delta H}{mC_p} = \frac{72,000}{(800)(1.02)} = 88^\circ\text{F}$$

$$T_{\text{final}} = 77 + 88 = 165^\circ\text{F}$$

5.145



Basis: 1 hour

An energy balance shows $Q = \Delta H$.

Enthalpy values from H-x chart for NaOH

Comp.	$\Delta \hat{H}$, Btu/lb sol'n
10% (70°F)	35
40% (100°F)	94
H ₂ O vapor (212°F)	1150

$$\frac{10,000 \text{ lb sol'n in}}{100 \text{ lb sol'n in}} \left| \frac{10 \text{ lb NaOH}}{100 \text{ lb sol'n in}} \right| \frac{100 \text{ lb sol'n out}}{40 \text{ lb NaOH}} = \frac{2500 \text{ lb sol'n out}}{10,000 \text{ lb sol'n in}}$$

$$\text{H}_2\text{O evap} = 7500 \text{ lb}$$

Energy Balance:

$$Q = 7,500 (1150) + 2500 (94) - 10,000 (35) = 8.515 \times 10^6 \text{ Btu}$$

$$\text{Steam req'd} = Q/\Delta \hat{H}_{\text{cond.}} = \frac{8.515 \times 10^6 \text{ Btu/hr}}{933.7 \text{ Btu/lb}} = \boxed{9140 \text{ lb/hr}}$$

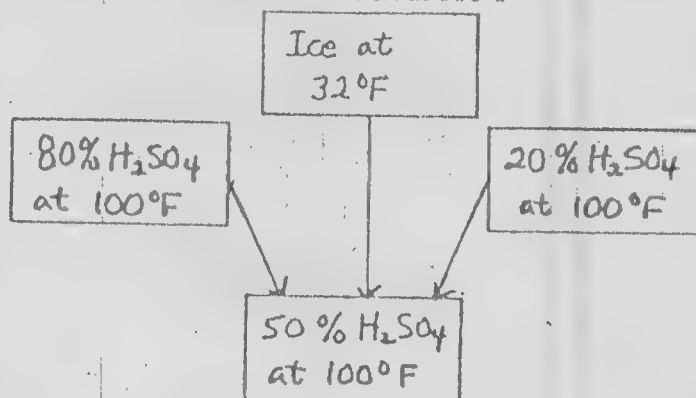
5.146

Use the enthalpy concentration diagram for H₂SO₄ (found in Appendix D) for the enthalpy data.

(continued)

Solutions-Chapter-5

Basis: 1000 lb 50% solution at 100°F



From Appendix I:

H ₂ SO ₄ Conc.	temp. (°F)	$\Delta \hat{H}$ (Btu/lb)
80%	100	-88
20%	100	-4
50%	100	-85

$\Delta \hat{H}$ of ice = -144 Btu/lb
(or negative of the heat of fusion)

Material Balance:

Let total lb of Feed 1 = x.

Component	Feed 1 (lb)	Feed 2 (lb)	Ice (lb)	Final sol'n (lb)	Wt. %
H ₂ SO ₄	0.8 x	500 - 0.8 x	0	500	50
H ₂ O	0.2 x	$\frac{500 - 0.8x}{0.2}$	$500 - 0.2x - \frac{500 - 0.8x}{0.2}$	500	50
Total	x	3000 - 4.8x	-2000 + 3.8x	1000	100

Energy Balance:

$$\Delta H_{\text{overall}} = 0 \quad \text{or} \quad \Delta H_{\text{in}} = \Delta H_{\text{out}}$$

$$\underbrace{-88 (\text{Feed 1 total}) + (-4) (\text{Feed 2 total}) + (-144) (\text{Ice total})}_{\text{In}} = \underbrace{-85 (1000 \text{ lb total})}_{\text{Out}}$$

Combine the material and energy balances to get:

$$-88x + (-4)(3000 - 4.8x) + (-144)(-2000 + 3.8x) = -85000$$

$$x = 586$$

The table can now be completed as follows:

(continued)

Solutions-Chapter-5

Component	Feed 1 (lb)	Feed 2 (lb)	Ice (lb)	Final sol'n (lb)	Wt. %
H ₂ SO ₄	468.8	31.2	0	500	50
H ₂ O	117.2	156.0	226.8	500	50
Total	586	187.2	226.8	1000	100

226.8 lb Ice at 32°F

586.0 lb 80% H₂SO₄ at 100°F

187.2 lb 20% H₂SO₄ at 100°F

5.147 The concentration lies on a line joining the coordinates of 0% H₂SO₄, ΔH = 1180, and 30% H₂SO₄ and 70°F. The intersection of this line with the boiling point line = 28%.

5.148 Basis: 1000 lb 10% NaOH at 100°F

a.	Conc.	lb NaOH	lb H ₂ O	total
Initial	10%	100	900	1000
Added	73%	0.73 m	0.27 m	m
Final	30%	100+0.73 m	900+0.27 m	1000 + m

$$\frac{100.0 + 0.73 m}{1000.0 + m} = 0.30$$

$$m = 465 \text{ lb 73\% NaOH added}$$

b. Reference State: liquid water at 32°F under its own vapor pressure (ΔH = 0 Btu/lb)

Enthalpy values from NaOH on H-x chart

$$Q = \Delta H = \Delta H_{30\%} - [\Delta H_{10\%} + \Delta H_{73\%}]$$

Conc.	Temp	lb sol'n	$\Delta \hat{H}$, Btu/lb	ΔH , Btu
10	100°F	1000	61	61,000
73	200°F	465	371	172,600
30	70°F	1465	37	54,200

$$Q = \Delta H = (54,200) - (61,000 + 172,600) = -179,400 \text{ Btu}$$

$$\Delta H_{\text{NaOH}} = -179,400 \text{ Btu}$$

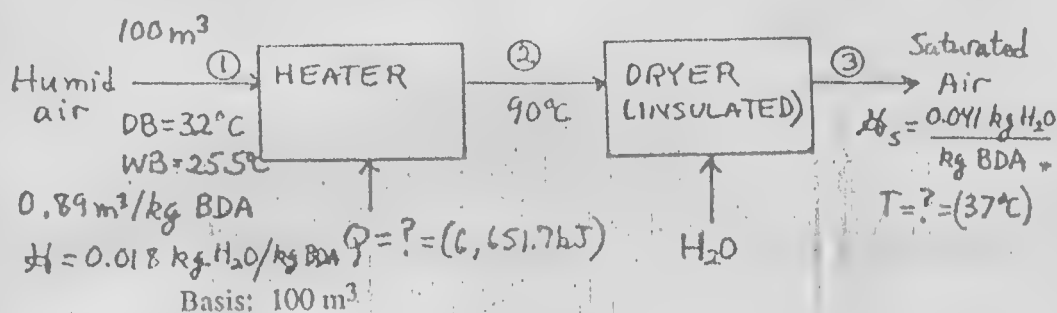
5.149 a. Dew point = 10°C

$$b. \%RH = \frac{P_{H_2O}}{P_{sat}} 100 = \frac{P_{10^\circ C}}{P_{27^\circ C}} 100 = \frac{9.209 \text{ kPa}}{26.739 \text{ kPa}} 100 = \boxed{34\%}$$

$$c. \%H = \frac{\left(\frac{P_{H_2O}}{P_{air}}\right)_{act}}{\left(\frac{P_{H_2O}}{P_{air}}\right)_{sat}} 100 = \frac{\left(\frac{P_{H_2O}}{P_t - P_{H_2O}}\right)_{act}}{\left(\frac{P_{H_2O}}{P_t - P_{H_2O}}\right)_{sat}} 100$$

$$= \frac{\left(\frac{9.209}{760 - 9.209}\right)}{\left(\frac{9.209}{760 - 26.739}\right)} 100 = \boxed{34\%}$$

5.150



Data from psychrometric chart (BDA = bone dry air).

a. @ 1, Dew point = $\boxed{23^\circ C}$ b. @ 1, humidity = $\boxed{0.018 \text{ kg H}_2\text{O} / \text{kg dry air}}$ c. @ 1, Relative humidity = $\frac{H}{H_s} = \frac{0.018}{0.033} (100) = \boxed{54.5\%}$ d. $\Delta H = Q + W$ $W = 0$

$$Q = \Delta H_2 - \Delta H_1 = (141.5 - 3.6) \frac{\text{kJ}}{\text{kg BDA}} - (79.0 - 0.3) \frac{\text{kJ}}{\text{kg BDA}} = 59.2 \frac{\text{kJ}}{\text{kg BDA}}$$

$$m = \frac{V}{V} = \frac{100 \text{ m}^3 \text{ entering air}}{0.89 \text{ m}^3} \frac{\text{kg BDA}}{\text{kg BDA}} = 112.36 \text{ kg BDA}$$

(continued)

Solutions-Chapter-5

$$Q = \frac{59.2 \text{ kJ}}{\text{kg BDA}} \left| \frac{112.36 \text{ kg BDA}}{\text{kg BDA}} \right| = \boxed{6,651.7 \text{ kJ}}$$

- e. Adiabatic cooling by evaporation yields a saturated humidity of 0.041 kg H₂O/kg BDA:

$$\frac{(0.041 - 0.018) \text{ kg H}_2\text{O}}{\text{kg BDA}} \left| \frac{112.36 \text{ kg BDA}}{110 \text{ m}^3 \text{ air}} \right| = \frac{\boxed{2.58 \text{ kg H}_2\text{O}}}{100 \text{ m}^3}$$

f. $T_{\text{exit}} = \boxed{37^\circ\text{C}}$

- 5.151 a. From Humidity Chart, where $t_{\text{DB}} = 90^\circ\text{C}$ (194°F) and $t_{\text{WB}} = 46^\circ\text{C}$ (115°F) $H = 0.049 \text{ kg H}_2\text{O/kg air}$. Upon cooling to 43°C (109°F), no condensation occurs, therefore H_m is constant.

$$\frac{0.049 \text{ kg H}_2\text{O}}{1 \text{ kg air}} \left| \frac{29 \text{ kg air}}{1 \text{ kg mol air}} \right| \left| \frac{1 \text{ kg mol H}_2\text{O}}{18 \text{ kg H}_2\text{O}} \right| = \frac{\boxed{0.079 \text{ kg mol H}_2\text{O}}}{\text{kg mol air}}$$

b. Final pressure = $100 \left(\frac{273 + 43}{273 + 90} \right) = 87.1 \text{ kPa}$.

c. At saturation: $0.079 = \frac{p^*_{\text{H}_2\text{O}}}{87.1 - p^*_{\text{H}_2\text{O}}}$; solving $p^*_{\text{H}_2\text{O}} = 6.38 \text{ kPa}$

At the dew point, the vapor pressure of pure water is equal to 6.38 kPa.
Dew point = $\boxed{37^\circ\text{C} (99^\circ\text{F})}$

The same answer can be obtained by proceeding to the dew point at H constant on a humidity chart for the correct pressure.

5.152 Assume $p_T = 760 \text{ mm Hg}$

a. $p^*_{\text{H}_2\text{O}} @ 120^\circ\text{F} = 87.58 \text{ mm Hg}$

$$H = \frac{(18)(87.58)}{(29)(672.42)} = \boxed{0.081 \text{ lb H}_2\text{O} / \text{lb dry air}}$$

b. From psychrometric chart, sat'd volume @ $120^\circ\text{F} = \boxed{16.52(\text{ft})^3 / \text{lb dry air}}$

c. From psychrometric chart, adiabatic cooling temp = wet bulb temp = $\boxed{77^\circ\text{F}}$

(continued)

d. $H @ 120^{\circ}\text{F} (\text{DP} = 60^{\circ}\text{F}) = 0.0110 \text{ lb H}_2\text{O}/\text{lb air}$

$H_{\text{sat}} @ 82^{\circ}\text{F} = 0.0237 \text{ lb H}_2\text{O}/\text{lb air}$

$$\% \text{ sat} = \frac{(0.0110)(100)}{(0.0237)} = \boxed{46.7\%}$$

e. $H_{\text{sat}} @ 60^{\circ}\text{F} = 0.01101 \text{ lb H}_2\text{O}/\text{lb dry air}$

$H_{\text{sat}} @ 40^{\circ}\text{F} = 0.00515 \text{ lb H}_2\text{O}/\text{lb dry air}$

$$0.01101 - 0.00515 = 0.00586$$

$$\frac{0.00586 \text{ lb H}_2\text{O}}{\text{lb dry air}} \left| \frac{98.9 \text{ lb dry air}}{100 \text{ lb moist air}} \right| = \boxed{0.579 \frac{\text{lb H}_2\text{O}}{100 \text{ lb moist air}}}$$

5.153

- a. The humidity of the entering air at 225°F DB and 110°F WB is obtained from the humidity chart.

$$\text{Humidity} = 0.031 \frac{\text{lb H}_2\text{O}}{\text{lb dry air}}$$

Assume the exit air to be saturated at 125°F .

$$\text{Humidity} = \boxed{0.0955 \frac{\text{lb H}_2\text{O}}{\text{lb dry air}}}$$

- b. Basis: 1 hr

$$\frac{10 \text{ tons}}{\text{day}} \left| \frac{1 \text{ day}}{24 \text{ hr}} \right| \left| \frac{2000 \text{ lb}}{\text{ton}} \right| = 835 \text{ lb/hr}$$

$$\text{Water in} = (0.1)(835) = 83.5 \text{ lb/hr}$$

$$\text{Water out} = \frac{(0.9)(835) \text{ lb dry grain}}{99 \text{ lb dry grain}} \left| \frac{1 \text{ lb H}_2\text{O}}{99 \text{ lb dry grain}} \right| = 7.59 \text{ lb/hr}$$

$$\text{lb H}_2\text{O removed/hr} = \text{water in} - \text{water out} = 83.5 - 7.59 = \boxed{75.9 \text{ lb H}_2\text{O/hr}}$$

c. Product output = $\left[(0.9)(835) \frac{\text{lb dry grain}}{\text{hr}} + 7.59 \frac{\text{lb H}_2\text{O}}{\text{hr}} \right] \left(\frac{24 \text{ hr}}{1 \text{ day}} \right) =$
 $\boxed{18,200 \text{ lb/day}}$

(continued)

Solutions-Chapter-5

$$d. \frac{\text{lb BDA}}{\text{hr}} = \frac{7.59 \text{ lb H}_2\text{O/hr}}{(0.0955 - 0.0310) \text{ lb H}_2\text{O/lb BDA}} = 1175 \text{ lb BDA/hr}$$

$$Q = \Delta H = \text{Enthalpy out} - \text{Enthalpy in}$$

$$= \Delta H_{\text{air}} + \Delta H_{\text{dry grain}} + \Delta H_{\text{water}}$$

$$1175 \frac{\text{lb BDA}}{\text{hr}} \left[136.5 \frac{\text{Btu}}{\text{lb BDA}} - (92.25 - 2.25) \frac{\text{Btu}}{\text{lb BDA}} \right]$$

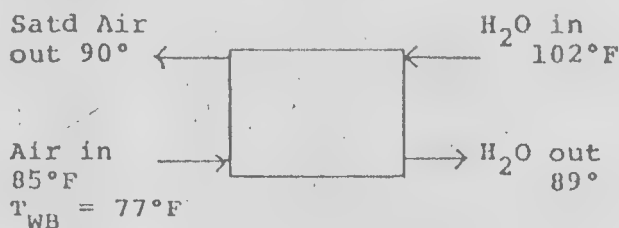
$$+ \frac{(0.9) (835) \text{ lb dry grain}}{\text{hr}} \left| \frac{0.18 \text{ Btu}}{(\text{lb}) (^\circ\text{F})} \right| (110 - 70) ^\circ\text{F}$$

$$+ \frac{7.59 \text{ lb H}_2\text{O}}{\text{hr}} \left| \frac{1.0 \text{ Btu}}{(\text{lb}) (^\circ\text{F})} \right| (110 - 32) ^\circ\text{F}$$

$$- \frac{83.5 \text{ lb H}_2\text{O}}{\text{hr}} \left| \frac{1.0 \text{ Btu}}{(\text{lb}) (^\circ\text{F})} \right| (70 - 32) ^\circ\text{F}$$

$$= 5.46 \times 10^4 + 0.54 \times 10^4 + 0.059 \times 10^4 - 0.32 \times 10^4 = \boxed{5.74 \times 10^4 \text{ Btu/hr}}$$

5.154 Data from Humidity Char



$$a. H_{\text{air in}} = \boxed{0.01813 \text{ lb H}_2\text{O/lb air}}$$

$$b. H_{\text{air out}} = \boxed{0.031 \text{ lb H}_2\text{O/lb air}}$$

$$\begin{aligned} \text{H}_2\text{O picked up} &= 0.031 - 0.01813 \\ &= 0.0129 \text{ lb H}_2\text{O/lb air} \end{aligned}$$

Energy Balance:

$$\Delta H_{\text{air out}} - \Delta H_{\text{air in}} = \Delta H_{\text{water in}} - \Delta H_{\text{water out}}$$

(continued)

Basis: 1 lb dry air

Ref. temp = 85°F

$$\frac{\Delta H_{\text{air out}}}{(1 \text{ lb})(90 - 85)} + \frac{\Delta H_{\text{H}_2\text{O out}}}{(0.031 \text{ lb})(90 - 85)}$$

$$\frac{\Delta H_{\text{H}_2\text{O out}}}{1 \text{ lb}} + \frac{\Delta H_{\text{air} + \text{H}_2\text{O in}}}{-0} = \frac{\Delta H_{\text{H}_2\text{O in}} - \Delta H_{\text{H}_2\text{O out}}}{(1 \text{ lb})(102 - 89)}$$

$$m = 1.136 \text{ lb H}_2\text{O/lb air or } 0.915 \text{ lb air / lb H}_2\text{O}$$

$$\text{c. } \% \text{ H}_2\text{O vaporized} = \left(\frac{0.0129}{1.136} \right) 100 = 1.14\%$$

5.155 Basis: 180 kg/hr of product

Material Balance

$$\text{Dry product} = \frac{92 \text{ kg dry P}}{100 \text{ kg P}} \times \frac{180 \text{ kg P}}{1 \text{ hr}} = 166 \text{ kg dry P/hr}$$

a. Water removed from solid:

$$\begin{aligned} \text{In} &= \frac{1.25 \text{ kg H}_2\text{O}}{1.00 \text{ kg dry P}} \times 166 \text{ kg/hr dry P} - (0.08)(180) \text{ kg/hr} \\ &= 207.5 - 14.4 = 193 \text{ kg H}_2\text{O/hr} \end{aligned}$$

Basis: 1 BDA

Water picked up in dryer

$$\begin{aligned} \left(\frac{0.0571 \text{ kg H}_2\text{O}}{\text{kg BDA}} \right)_{\text{out}, 53^\circ} - \left(\frac{0.0083 \text{ kg H}_2\text{O}}{\text{kg BDA}} \right)_{\text{in}, 21^\circ} &= 0.0488 \frac{\text{kg H}_2\text{O}}{\text{kg BDA}} \\ \frac{\text{kg BDA}}{\text{hr}} &= \frac{193 \text{ kg H}_2\text{O}}{0.0488 \text{ kg H}_2\text{O/kg BDA}} = 3955 \text{ kg BDA/hr} \end{aligned}$$

(continued)

b. Energy balance

$\Delta \hat{H}$:	$\Delta \hat{H}$ (kJ/kg BDA)	
air in (21°C, 52% RH):	58.2	
air out (53°C, 60% RH):	219.7	
$\Delta \hat{H} =$	161.5	kJ/kg BDA

Basis: 1 hr

$$\Delta H = (161.6)(3955) = 6.387 \times 10^5 \text{ kJ}$$

Solid (ref. 21°C)

$$\text{solid out: } \Delta \hat{H} = \int_{21}^{43} C_p dT = \frac{0.18 \text{ cal}}{(\text{g}) (\text{°C})} \left| \frac{4.184 \text{ J}}{\text{cal}} \right| \left| \frac{10^3}{10^3} \right| (43 - 21) \text{ °C} = 16.57 \text{ kJ/kg P}$$

solid in: $\Delta \hat{H} = 0$ (because of reference temperature)

Basis: 1 hr

$$\Delta H = (16.57)(180) = 2983 \text{ kJ}$$

If the dryer and reheater are insulated, then for the system

$$Q - W = \Delta H \quad \text{and} \quad W = 0$$

$$Q_{\text{reheater}} = 2983 + 6.387 \times 10^5 = \boxed{6.42 \times 10^5 \text{ kJ/hr}}$$

5.156

Initial air: $T_{DB} = 38^\circ\text{C}$, $T_{WB} = 27^\circ\text{C}$,

$$H_1 = 0.0175 \text{ kg/kg dry air}$$

Air from scrubber: $T = 24^\circ\text{C}$, $RH = 100\%$, $H_2 = 0.0188 \text{ kg/kg dry air}$ Heated to 93°C : $H_3 = 0.0188$ From drier: $T_{DB} = 49^\circ\text{C}$, $H_4 = 0.0377$

(continued)

Solutions-Chapter-5

$$(1000 \text{ kg/hr}) (0.05) = 50.0 \text{ kg H}_2\text{O to be evaporated}$$

$$50.0 / (0.0377 - 0.0188) = 2650 \text{ kg dry air/hr}$$

$$2650 (0.0377) = 100 \text{ kg H}_2\text{O/hr}$$

$$V_4 = \left(\frac{2650}{29} + \frac{100}{18} \right) \left| \frac{22.4}{273} \right| \frac{273 + 49}{273} = 2560 \text{ m}^3 \text{ at } 49^\circ\text{C and 1 atm}$$

Heat supplied:

$$Q = [(2650) (1.00) + 100 (0.200)] (93 - 24) = 1.84 \times 10^5 \text{ kJ/hr}$$

Water at 93°C has $p^* = 79.4 \text{ kPa}$

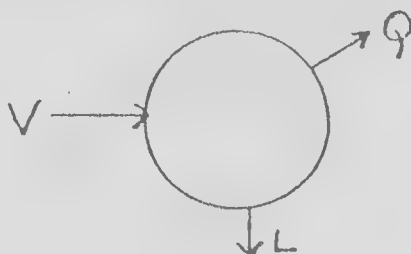
$$H_3 = \frac{(18)}{(29)} \left| \frac{(79.4)}{(101.3 - 79.4)} \right| = 2.25 \text{ kg H}_2\text{O/kg dry air}$$

$$[(0.0188/2.25)] (100) = 0.83\% \quad RH \text{ air from heater}$$

Answers:

- | | | | |
|----|-----------------|-----------|-------------------------------------|
| a. | 1. $H = 0.0175$ | b. 1. 42% | c. 2650 kg dry air/hr |
| | 2. $H = 0.0188$ | 2. 100% | d. $2560 \text{ m}^3/\text{hr}$ |
| | 3. $H = 0.0188$ | 3. 0.83% | e. $1.84 \times 10^5 \text{ kJ/hr}$ |
| | 4. $H = 0.0377$ | 4. 47% | |

6.1

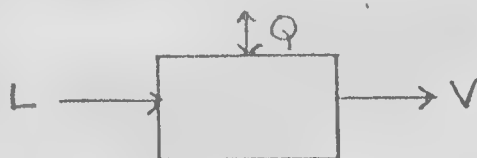


Total variables (2 streams + Q) $2(c + 1) + 1 = 2c + 5$

Constraints

indept. material balances	c	
energy balance	1	$\frac{c+1}{c+4}$
Net d.f		

6.2



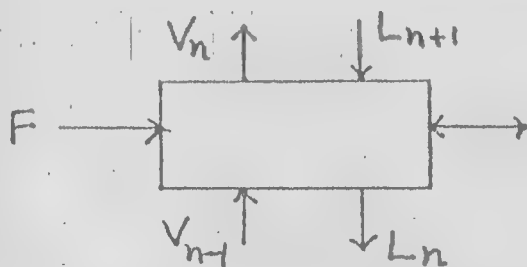
Total variables (2 streams + Q) $2(c + 2) + 1 = 2c + 5$

Constraints

indept. material balances	c	
energy balance	1	$\frac{c+1}{c+4}$
Net d.f		

Conventional specifications of variables are the entering stream ($c + 2$), and the temperature (1) of the exit stream. In some instances Q (1) may be specified rather than the outlet temperature.

6.3



Assume the feed is a single phase stream not the same as any of the other streams.

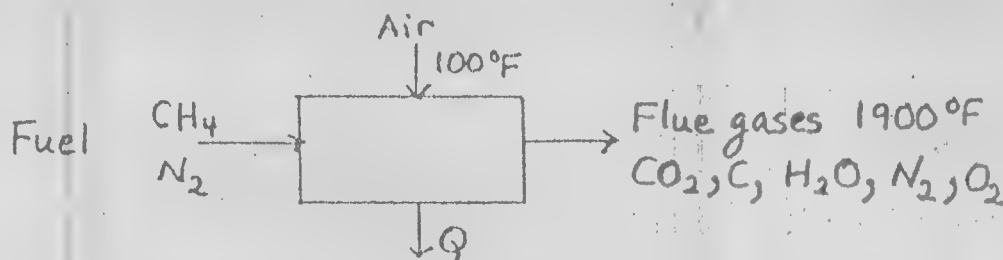
(Continued)

Total variables (5 streams + Q) $5(c + 2) + 1 = 5c + 11$

Constraints:

Indept. material balances	c	
Energy balance	1	
Equilibrium relations	c	
T same in each phase	1	
p same in each phase	1	$\frac{2c+3}{3c+8}$
Net d.f.		

6.4



The components are 6: CH_4 , CO_2 , CO , H_2O , N_2 , O_2 . Hence, the total no. of variables is for 3 streams + Q $3(4 + 2) + 1 = 19$

We can reduce these variables by

Note: the true number of phase rule components = 4

- | | | |
|-----|--|---|
| (1) | Material balances (C, H, O, N) | 4 |
| (2) | Energy balance | 1 |
| (3) | Concentrations of component specified in | |
| | fuel | 3 |
| | air | 2 |
| | flue gas | 0 |

- | | | |
|-----|---|----|
| (4) | Specification of % excess air (stream flow) | 1 |
| (5) | Specification of 3 temperatures | 3 |
| | | 14 |

$$19 - 14 = 5$$

Three pressures must be specified and one extensive variable: feed, air, or flue gas. The last variable would be the ratio of CO to CO_2 .

6.5 Each stage has $2c + 6$ variables. Hence, there are $N(2c + 6)$ variables + 1 for the decision as to the value of N. There are $2(N - 1)$ interstreams and thus $2(N - 1)(c + 2)$ restrictions as streams are combined.

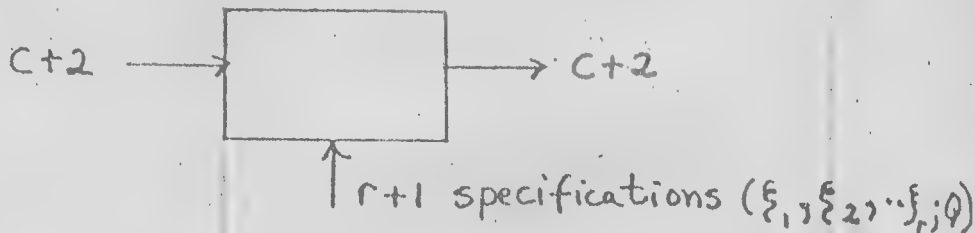
$$\text{D.f.} = \{N(2c + 6) + 1\} - \{2(N - 1)(c + 2)\} = 2c + 2N + 5$$

(Continued)

The variables to be specified might be

pressure in each stage	N
Q in each stage	N
F in each stage	c + 2
S in each stage	c + 2
N in each stage	1
	2N + 2c + 5

- 6.6 Assume phase equilibrium exists, if more than one phase occurs. With r reactions, we have $\xi_1, \xi_2, \dots, \xi_r$ values specified.



We trade r equilibrium relations for the r extent of reactions, and the degrees of freedom are $C+2 - (r+1) = C-r+1$

- 6.7 24 variables - (3) (5) equations = 9 less 4 specifications
 = 5 more specifications
 (the equations are energy, mass, equilibria.)

- 6.8 a. A set of differential equation can be written for each stage for each component (and total material).

For the steady state, you can write overall balances
 total mass balance
 NH_3 balance
 H_2O balance
 sum of mass fraction balances for F, D, B

If a basis is picked, such as $F = 100$, 2 unknowns exist, D and B, and two independent equations exist; hence the system is determinate.

(Continued)

For the sequence of stages, each stage would have:
 total material balance
 component material balances
 equilibrium relations
 sum of mass (mole) fraction relations

In total, there would be 6 independent equations and 8 unknown variables on the top stage. The bottom stage would have 7 independent equations and 7 unknowns. Starting at the bottom, each successive stage would be determinate until the top was reached. Without equilibrium relations holding and without knowing enthalpies as a function of concentration, the number of unknowns would exceed the number of independent equations.

- b. Examine unit 1 in as much as no feedback of information occurs. If unit 1 is not determinate, the entire system will not be determinate. The balances for unit 1 are

$$\left. \begin{array}{l} \text{total} \\ \text{alcohol} \\ \text{inerts} \\ \text{equilibrium} \\ y_{1o} + y_{1a} = 0.90 \end{array} \right\} 4 \text{ independent equations}$$

The unknowns are 5

$$V_1, L_1, S_o, y_{1o}, y_{1a}$$

Thus, the subsystem is not determinate.

6.9

$$N_v = 3(5 + 2)$$

21

N_r :

Material balances

5

Vapor-liquid equilibria relations

4

(One pair, $x_{35} = K_5 x_{25}$, is known and redundant.)

T's and p's are equal

4

Specified values of variables

7

($F_1, x_{11}, x_{12}, x_{13}, x_{14}, T, p$)

20

1 = d.f. (under specified)

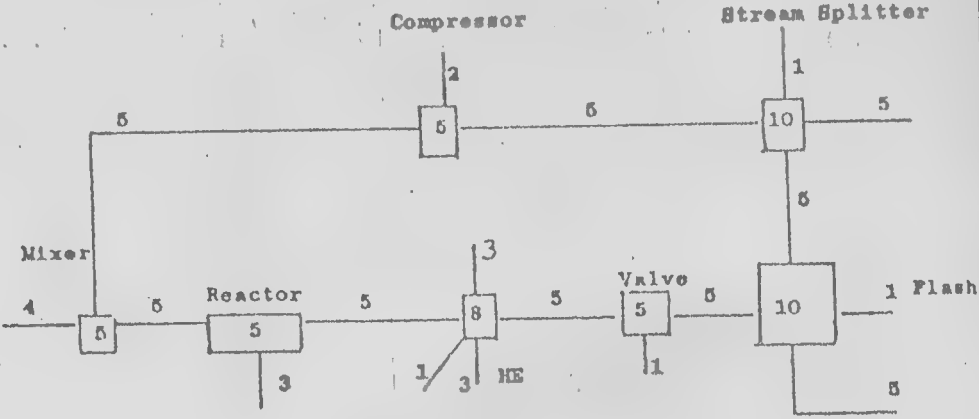
6.10

Four of the material balance equations are redundant (3 or 13, 8 or 12, 9 or 16, 14, or 15), hence there are 27 independent equations and 34 variables yielding 7 degrees of freedom. Certain of the process variables must be specified, namely the temperatures of the entering streams (T_1, T_4 and T_6), and the flow rate and composition of the exit stream which must meet preset values thus fixing the values of $F_7, x_{1,7}, x_{2,7}, x_{3,7}$ and $x_{4,7}$. However, only three of these four exit

(Continued)

mole fractions are independent (because the summation of mole fraction must be unity) and may be specified. Therefore, all of the 7 degrees of freedom are absorbed by the specifications. Thus the problem is properly specified, and can be solved by one of the techniques cited in Appendix L, given a set of values for the coefficients C_i , A , U , and ρ_i plus the values of the 7 specified variables.

6.12



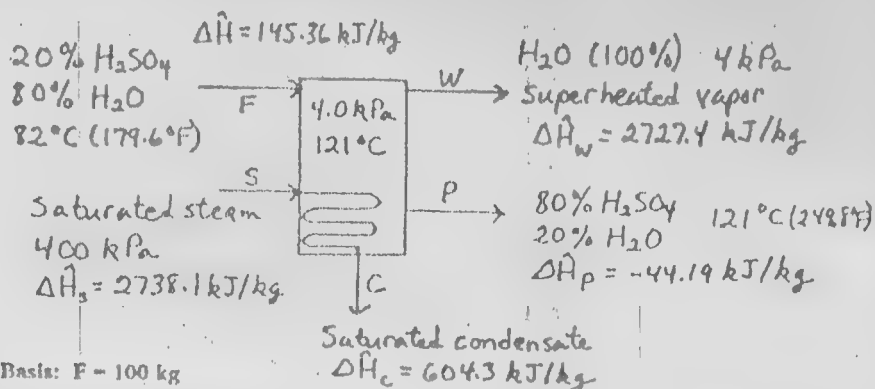
Basic Block Diagram for the Flowsheet

Unit	Equations	Stream Variables	Unit Parameters
Mixer	5	9	0
Reactor	5	5	3
Cooler	8	8	1
Valve	5	5	1
Flash	10	5	1
Bleed	10	5	1
Compressor	5	5	2
<u>Streams Leaving</u>		<u>Stream variables</u>	
Cooling Water		3	
Product		5	
Bleed Stream		5	

Total Equations	48		
Stream Variables		55	
Unit Parameters			9
Total Variables			64
The flowsheet has			

$$64 - 48 = 16 \text{ degrees of freedom}$$

6.13

DataW (interpolating from SI steam tables)

$$\Delta \hat{H}_W = 2644.0 \frac{\text{kJ}}{\text{kg}} + \frac{(2738.8 - 2644.0) \frac{\text{kJ}}{\text{kg}} (394 - 350) \text{K}}{(400 - 350) \text{K}} = 2727.4 \frac{\text{kJ}}{\text{kg}}$$

F

$$\Delta \hat{H}_F = \frac{62.5 \text{ Btu}}{\text{lb}} \left| \frac{1.055 \text{ kJ}}{\text{Btu}} \right| \frac{1 \text{ lb}}{0.4536 \text{ kg}} = 145.36 \frac{\text{kJ}}{\text{kg}}$$

P

$$\Delta \hat{H}_P = \frac{-19.0 \text{ Btu}}{\text{lb}} \left| \frac{1.055 \text{ kJ}}{\text{Btu}} \right| \frac{1 \text{ lb}}{0.4536 \text{ kg}} = -44.19 \frac{\text{kJ}}{\text{kg}}$$

Unknowns: $W, P, S = C$ Balances: $\text{H}_2\text{SO}_4, \text{H}_2\text{O}$ (or overall), energy H_2SO_4 Balance:

$$\frac{F \text{ kg Feed} \left| \frac{20 \text{ kg } \text{H}_2\text{SO}_4}{100 \text{ kg Feed}} \right|}{100 \text{ kg Feed}} = \frac{P \text{ kg Product} \left| \frac{80 \text{ kg } \text{H}_2\text{SO}_4}{100 \text{ kg Product}} \right|}{100 \text{ kg Product}}$$

$$0.2 (100 \text{ kg}) = 0.8 P$$

$$P = 25 \text{ kg}$$

(Continued)

Overall Mass Balance:

$$F_{\text{kg feed}} + S_{\text{kg steam}} = W_{\text{kg vapor}} + P_{\text{kg product}} + C_{\text{kg condensate}}$$

$$F + S = W + P + C$$

$$F = W + P$$

$$(100 \text{ kg}) = W + 25 \text{ kg hence } W = 75 \text{ kg H}_2\text{O vapor}$$

Overall Energy Balance Reduces to (Open System, Steady State):

$$\Delta H = 0$$

$$m(\Delta H_C - \Delta H_S) + (m_W \Delta H_W + m_P \Delta H_P - m_F H_F) = 0$$

$$\frac{m}{\text{kg}} \left| \frac{(604.3 - 2738.1) \text{ kJ}}{\text{kg}} + \frac{75 \text{ kg}}{\text{kg}} \left| \frac{2727.4 \text{ kJ}}{\text{kg}} + \frac{25 \text{ kg}}{\text{kg}} \left| \frac{-44.19 \text{ kJ}}{\text{kg}} - \frac{100 \text{ kg}}{\text{kg}} \left| \frac{145.36 \text{ kJ}}{\text{kg}} \right. \right. \right. = 0$$

$$-2,133.8 m \text{ kJ/kg} + 204,555 \text{ kJ} - 1,104.75 \text{ kJ} - 14,536 \text{ kJ} = 0$$

$$m = \frac{188,914.751 \text{ kJ}}{88.5 \text{ kg steam}} \left| \frac{100.0 \text{ kg feed}}{\text{kg steam}} \right. = 1,129.5 \text{ kg feed}$$

6.14 $T_3 = 109.34^\circ\text{F}$

$T_4 = 86.44^\circ\text{C}$

F_3	Components	lb mol/hr
	A	143.01
	B	58.78
	C	35.78

6.15 Basis: 1 hr

Eqn. No.

(1) Turbine Material Balance

$$A = B + C$$

(2) Turbine Energy Balance

$$200,000 = \frac{1482A - 1406B - 1164C \text{ Btu}}{\text{hr}} \left| \frac{1 \text{ hp}}{2.55 \times 10^3 \text{ Btu/hr}} \right.$$

(continued)

$$20,000 = (B/30) + (C/8)$$

(3) 600-psi Material Balance

$$B = 100,000 + 100,000 + D + 30,000$$

$$B = D + 230,000$$

(4) 50-psi Material Balance

$$F + D + 30,000 = E$$

(5) 50-psi Energy Balance

$$1,380 D + 30,000 (1,300) + 218 F = 1,210 E$$

(6) Deaerator Material Balance

$$E + C + 200,000 = A + F$$

(7) Deaerator Energy Balance

$$1,210 E + 68 (C + 200,000) = 218 (A + F)$$

There are 7 eqns. and 6 unknowns.

$$\text{Combine (4) \& (6): } A - C - D = 230,000 \quad (8)$$

$$\text{" (4) \& (7): } 218 A - 68 C - 218 D - 992 E = 20,140,000 \quad (9)$$

$$\text{" (4) \& (5): } 1162 D + 32,460,000 = 992 E \quad (10)$$

$$\text{Combine (8) \& (1): } B - D = 230,000 \quad (11)$$

$$\text{" (9) \& (1): } 218 (B + C) - 68 C - 218 D - 992 E = 20,140,000 \quad (12)$$

$$\text{" (10) \& (12): } 218 B + 150 C - 1380 D = 52,600,000 \quad (13)$$

Solving eqns. (2), (11) & (13) simultaneously:

$$B = 240,266 \text{ lb/hr}$$

$$C = 95,929 \text{ lb/hr}$$

$$D = 10,266 \text{ lb/hr}$$

Substituting D in eqn. 10:

$$E = 44,747 \text{ lb/hr}$$

" D & E in eqn. 4:

$$F = 4,481 \text{ lb/hr}$$

" B & C in eqn. 1:

$$A = 336,195 \text{ lb/hr}$$

A calciner presents a classic choice between air preheat and waste-heat boilers. The goal is to reduce the consumption of natural gas. Only about the 50×10^6 Btu/hr are being absorbed into the process. A rough calculation gives

		(Btu/hr)(10 ⁻⁶)
Feed heating:	$200,000 \times 0.5 \times (500 - 200)^\circ\text{F}$	= 25
Water vaporization:	$20,000 \times 970$	= 19.4
Water heating:	$20,000 \times 0.5 \times (1,000 - 500)$	= 5.0
Total		49.4

About 150×10^6 are available in the fuel.

Preheating the air

Preheating the air to 560°F will cool the flue gas to about 500°F , and no condensation should occur. The duty of the preheater would be $400,000 \times 0.24 (560 - 60) = 48$ million Btu/hr. The exhaust flue gas from the air preheater could be used to generate steam or to preheat feed (in a direct-contact fluid bed, for example), and the product solids might also be put to use. Either holds the potential for another 20 million Btu/hr savings if a use can be found for the recovered steam or heat.

Waste heat boiler

About 52,000 lb/hr of 630-psig steam could be generated. This could be used to preheat the feed and perhaps do some of the water vaporization, but this amounts to replacing the calciner--a high-capital-cost route. The steam could also be used to preheat the combustion air to about 450°F . This would utilize $400,000 \times 0.24 \times (450 - 60) = 37.4$ million Btu/hr.

Capital costs of the respective equipment must be considered. Usually the capital cost for air preheat systems are less. In addition, credits are surer, since fuel is conserved directly. The value of the heat saved does not depend on the overall site steam balance. On the other hand, steam is more flexible and far more portable than large volumes of hot gas. Preheated combustion air changes the combustion characteristics and the radiant-heat distribution of a furnace and can increase emissions of nitrogen oxides. The addition of hot-air ducts can sometimes cause access problems under a furnace and may in fact become uneconomical for furnaces with a large number of wall burners.

(Continued)

6.17

Basis: 1 g mol CaCO_3 

$$\Delta \hat{H}_f^\circ \left(\frac{\text{k cal}}{\text{g mol}} \right) \quad -288.45 \quad -151.9 \quad -94.052$$

$$\Delta H^\circ_{\text{Rxn}} = 1(-151.9) + 1(-94.052) - 1(-288.45) = 42.50 \text{ k cal/g mol CaCO}_3$$

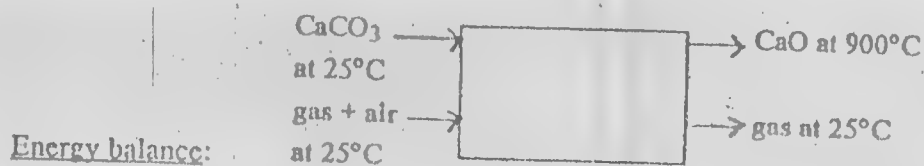
$$= 177.8 \text{ kJ/g mol}$$

Basis: 1 g mol CH_4 

$$\Delta \hat{H}_f^\circ \left(\frac{\text{k cal}}{\text{g mol}} \right) \quad -212.80 \quad 0 \quad 0 \quad 0$$

$$\Delta H^\circ_{\text{Rxn}} = -[-(-212.80)] = -212.80 \text{ k cal/g mol CH}_4$$

$$= -890.36 \text{ kJ/g mol}$$



$$Q + W = -\Delta H \quad \text{or } \Delta H = 0 \quad \text{Ref. } T = 25^\circ\text{C} \quad Q = 0, W = 0$$

Basis: 1 g mol CaCO_3

$$\Delta H_{\text{CaO}} = \frac{111 \text{ J}}{(\text{g mol})(^\circ\text{C})} \bigg|_{(900-25)^\circ\text{C}} = 97.125 \text{ kJ/g mol CaO}$$

Let X be the g mol $\text{CH}_4/\text{g mol CaCO}_3$

CaO	gases	CaCO_3	gas	air	Reactions
[(1) (97.125) + 0]	- [0 +	0 +	0]	+ [(1) (177.8) + X (-890.36)]	= 0

(Continued)

$$X = 0.309 \text{ g mol CH}_4/\text{g mol CaCO}_3$$

$$\frac{1 \text{ g mol CaCO}_3}{0.309 \text{ g mol CH}_4} \left| \frac{100 \text{ g CaCO}_3}{1 \text{ g mol CaCO}_3} \right| \frac{1 \text{ g mol CH}_4}{16 \text{ g CH}_4} \left| \frac{10^3}{10^3} \right| = 20.2 \frac{\text{kg CaCO}_3}{\text{kg CH}_4}$$

6.18

Basis: 1 hr

Material balance

In	lb	Out	lb
Salt (16,000) (.07)	= 1,120	Salt	= 1,120
Water 16,000 - 1,120	= 14,880	Water soln $1,120 - \frac{1,120}{0.4}$	= 1,680
		Water evap: 14,880 - 1,680	= 13,200

(a) Energy balance

Basis: 180°F, liq. H₂O

In	Btu
7% Solution = (0.92) (16,000) (T - 180)	= 14,720 (T - 180)
Steam ΔH_{vap} = (15,000) (959)	= 14,400,000
Liq. H ₂ O = (15,000) (1.0) (230 - 180)	= 750,000
	15,150,000 + 14,720 (T - 180)
<u>Out</u>	
H ₂ O vapor ΔH_{vap} = (13,200) (990)	= 13,070,000
Condensate = 15,000 (230 - 180)	= 750,000
Conc. salt soln =	= 0
	13,820,000

$$15,150,000 + 14,720 (T - 180) = 13,820,000$$

$$T = 90^\circ\text{F}$$

The above analysis ignores the heat of solution effects as the NaCl becomes more concentrated.

(b) 2,800 lb 40% NaCl produced/hr

6.19

Phase I: Material Balances

Basis: 10,000 lb/hr of mash

(a) Material balance around column I and condenser:

In		Out	
Feed	{ A	Product { A	= 1,000 lb
	{ H ₂ O		
	{ M		
	(0.10)(10,000) = 1,000 lb		
	(0.80)(10,000) = 8,000 lb	(1000) - 1000 =	667 lb
	(0.10)(10,000) = 1,000 lb	(8000 - 667)	= 7,333 lb
		{ M	= 1,000 lb
		Bottoms	10,000 lb

(b) Material balance around column I only:

Feed	{ A	= 1,000 lb
	{ H ₂ O	= 8,000 lb
	{ M	= 1,000 lb
Reflux	{ A	(3)(1000) = 3,000 lb
	{ H ₂ O	(3)(667) = 2,000 lb
		15,000 lb

(c) Material balance around column II and condenser:

Feed	{ A	= 1,000 lb
	{ H ₂ O	= 667 lb
(d) Overhead product	{ A	= 1,000 lb
	{ H ₂ O	(1000 - 1000) = 50 lb
	{ H ₂ O	(667 - 50) = 617 lb
Bottoms		1,667 lb

(d) Material balance on column II cutting reflux and overhead vapor:

Feed	{ A	= 1,000 lb
	{ H ₂ O	= 667 lb
(e) Reflux	{ A	3(1000) = 3,000 lb
	{ H ₂ O	(3)(50) = 150 lb
		4,817 lb

(continued)

(c) Energy balance around heat exchanger I outlet and overhead vapor and reflux from II:

	In	Out
Feed to II	$1667(0.85)(176 - 172) =$	Vapor $4200(0.72)(172 - 172) + 4200(650) = 2,725,000$
	$\Delta H_{\text{vaporization steam at } 176^\circ\text{F}}$	
	$+1667(675)$	
Reflux	$3150(0.72)(160 - 172) =$	Bottoms $617(1.0)(210 - 172) = 23,400$
Steam	ΔH_{S}	ΔH_{S}
	$\Delta H_{\text{S}} + 1,103,450$	$2,748,400$
	$\Delta H_{\text{S}} + 1,103,450 = 2,748,400$	
	$\Delta H_{\text{S}} = 1,645,000 \text{ Btu/hr}$	

(d) Total energy input into system:

$$\Delta H_{\text{S}} + \Delta H_{\text{S}} + \text{steam heater} = 4,842,000 + 1,645,000 + 1,125,000 = 7,612,000 \text{ Btu/hr} \rightarrow \text{c}$$

(c) Energy balance on condenser I:

	In	Out
Vapor	$6667(0.85)(176 - 172) + (6667)(575) =$	Condensate $6667(0.85)(176 - 172) =$
Cooling H ₂ O	$W(1.0)(80 - 176)$	Cooling H ₂ O $W(1.0)(130 - 176) =$
	$-96W$	$-96W$
	$50W = 4,500,000$	$W = \frac{4,500,000}{50} = 90,000 \text{ lb H}_2\text{O/hr}$
	$90,000 \text{ lb H}_2\text{O/hr} = 10,800 \text{ gal H}_2\text{O/hr} \rightarrow \text{d}_1$	
	$\frac{90,000 \text{ lb H}_2\text{O/hr}}{8.345 \text{ lb/gal}}$	

(continued)

(U) Energy balance on condenser II:

$$M = 18 \text{ H}_2\text{O/hr.}; \quad \text{Reference temperature} = 172^\circ\text{F}$$

	J_n	
Vapor	$4200(0.72)(172 - 172) + (4200)(650)$	$= 2,725,000$
Cooling H ₂ O	$W(1.0)(80 - 172)$	$= \frac{-92W}{-92W + 2,725,000}$
Condensate	$4200(0.72)(160 - 172)$	$= -36,000$
Cooling H ₂ O	$W(1.0)(172 - 130)$	$= -42W$
		$-42W - 36,000$

$$50W = 2,761,000 \quad \text{or} \quad W = \frac{2,761,000}{50} = 55,200 \text{ lb H}_2\text{O/hr}$$

$$\frac{55,200 \text{ lb } H_2O}{8.345 \text{ lb/gal}} = 6620 \text{ gal } H_2O/\text{hr} \quad (\text{d})$$

(g) Energy balance on heat exchanger II:-

$W = 1 \text{ lb H}_2\text{O/hr}$; Reference temperature = 80°F

Condensate	$1050(0.72)(160 - 80)$	$= 60,500$	
Cooling H ₂ O	$W(1.0)(80 - 80)$	$= 0$	
		<u>60,500</u>	

$$50W + 15,120 = 60,500$$

$$W = 907 \text{ lb H}_2\text{O/hr} \quad \text{or} \quad 109 \text{ gal H}_2\text{O/hr} \leftarrow$$

(continued)

Phase 2: Energy Balances

(a) Energy balance on heat exchanger III (Fig. E5.15b):

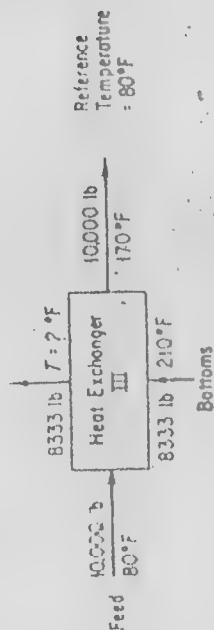


Fig. E5.15b

In		Out	
Feed	$(10,000)(0.96)(80 - 80) = 0 \text{ Btu}$	Feed	$(10,000)(0.96)(170 - 80) = 864,000 \text{ Btu}$
Bottoms	$(8,333)(1.0)(210 - 80) = 1,084,000 \text{ Btu}$	Bottoms	$(8,333)(1.0)(T - 80) = (8,333T - 666,000) \text{ Btu}$
	$1,084,000 = 8,333T - 666,000 + 864,000$		
	$886,000 = 8,333T$		
	$T = 106.5^\circ\text{F}$		

(b) Energy balance around heat exchanger III inlet, and overhead vapor and reflux line from I:

In		Out	
Feed	$10,000(0.96)(80 - 176) = -921,000$	Bottoms to vanillin plant	$8,333(1.0)(106.5 - 176) = -579,000$
Reflux	$5000(0.85)(176 - 176) = 0$	Vapor	$6667(0.85)(176 - 176) + 6667(675) = 4,500,000$
Steam	ΔH_S		
	$\Delta H_S - 921,000$		$3,921,000$
	$\Delta H_S - 921,000 = 3,921,000$		
	$\Delta H_S = 4,842,000 \text{ Btu/hr}$		

(continued)

6.20

$\Delta \hat{H}^\circ_f$ (kJ/g mol):	-224.4	+12.00	0
mol. wt.:	100	92	2.016

$$\Delta \hat{H}^\circ_{Rxn} = 12.00 - (-224.4) = 236.4 \text{ kJ/g mol heptane}$$

Basis: 100 kg n-C₇H₁₆Material balance:

		kg	kg mol
In: n-C ₇ H ₁₆		100	1.00
Out: toluene	(1.00) (0.15) (92) =	13.8	0.15
H ₂	(1.00) (0.15) (4) (2.02) =	1.21	0.60
n-C ₇ H ₁₆	(100) (0.85) =	85.0	0.85
		100.0	

Energy Balance on reactor: $\Delta H_{\text{prod}} - \Delta H_{\text{react}} + \Delta H_{Rxn} = Q$

(continued)

Solutions - Chapter 6

	m	C _p	ΔT	kJ
n-C ₇ H ₁₆ vapor	100	(1.88)	(425 - 98.6)	61,360
ΔH _{vap} at 98.6°C	(100)	(318)		31,800
n-C ₇ H ₁₆ liquid	100	(2.13)	(98.6 - 25)	<u>15,680</u>
				<u>108,840</u>
n-C ₇ H ₁₆ vapor	85.0	(1.88)	(425 - 98.6)	52,160
ΔH _{vap} at 98.6°C	85.0	(318)		27,030
n-C ₇ H ₁₆ liquid	85.0	(2.13)	(98.6 - 25)	13,330
Toluene vapor	13.8	(2.30)	(425 - 110.8)	9,970
ΔH _{vap} 110.8°C	13.8	(364)		5,020
Toluene liquid	13.8	(2.22)	(110.8 - 25)	2,630
H ₂ (g)	0.60	[29.2 (425 - 0) - (28.7) (25.0)]		<u>7,410</u>
				<u>117,550</u>

$$\Delta H_{Rxn} = (1000) (236.4) (0.15) = 35,460 \text{ kJ}$$

$$Q = 117,550 - 108,840 + 35,460 = 44,170 \text{ kJ/100 kg n-heptane fed}$$

Energy Balance on extractor (ref. 25°C)

10 kg of solv. is used per kg of Toluene
 so solvent used = $10 \times 13.8 = 138 \text{ kg}$
 amount 138 kg

n-C ₇ H ₁₆	85	(2.13)	(18 - 25)	-1,267
toluene	13.8	(2.22)	(18 - 25)	- 215
solvent	138	(1.67)	(38 - 25)	<u>2,996</u>
				<u>1,514</u>

n-C ₇ H ₁₆	85	(2.13)	(T - 25)	
toluene	13.8	(2.22)	(T - 25)	442.15 (T - 25)
solvent	138	(1.67)	(T - 25)	

at of Solution: (-23 kJ/kg) (13.8) -317

$$\Delta H_{prod} - \Delta H_{react} + \Delta H_{soln} = 0$$

$$442.15 (T - 25) - 1,514 + (-317) = 0$$

(continued)

$$T = 29.14^{\circ}\text{C}$$

(c) Energy Balance on heat exchanger: (ref. 29.14°C)

(Assume fresh solvent is negligible in quantity.)

			kJ
<u>In:</u>	toluene	$13.8 (2.22) (29.14 - 29.14)$	0
	solvent	$138 (1.67) (29.14 - 29.14)$	0
	solvent	$138 (1.67) (120 - 29.14)$	<u>20,940</u>
			20,940
<u>Out:</u>	toluene	$13.8 (2.22) (T - 29.14)$	
	solvent	$138 (1.67) (T - 29.14)$	= $261 (T - 29.14)$
	solvent	$138 (1.67) (38 - 29.14)$	2,040
			$2,040 + 261 (T - 29.14)$

$$20,940 = 2,040 + 261 (T - 29.14)$$

$$T = 102^{\circ}\text{C}$$

(d) Energy Balance on still: (ref. 111°C , i.e., where ΔH_{vap} for toluene is given)

Assume the toluene vapor leaves at 120°C .

(continued)

			<u>kJ</u>
In:	Solvent	138 (1.67) (100 - 111)	-2,535
	toluene	13.8 (2.22) (100 - 111)	- <u>337</u>
			<u>-2,872</u>
Out:	solvent	138 (1.67) (120 - 111)	2074
	toluene	13.8 (2.30) (120 - 111)	<u>286</u>
			<u>2360</u>

ΔH_{vap} of toluene assuming all entering the still vaporizes:

$$13.8 (364) \quad 5023$$

$$Q = \Delta H = \Delta H_{\text{out}} - \Delta H_{\text{in}} + \Delta H_{\text{vap}}$$

$$= 2360 - (-2872) + 5023 = 10,260 \text{ kJ/100 kg}$$

$$= 103 \text{ kJ/kg n-heptane}$$

6.21 Base temp. = 70°F

a. Material Balance:

$$\text{Benzene:} \quad (100,000) (0.50) = 50,000 \text{ lb}$$

$$\text{Toluene:} \quad (100,000) (0.40) = 40,000 \text{ lb}$$

$$\text{o-Xylene:} \quad (100,000) (0.10) = 10,000 \text{ lb}$$

$$\text{Tower 1: overhead} = 50,000/0.96 = 52,100 \text{ lb Bz. + toluene}$$

$$\text{Residue: } 47,900 \text{ lb}$$

$$\text{Tower: 2 residue} = 10,000/0.99 = 10,100 \text{ lb o-xyl + tol.}$$

$$\text{overhead} = 47,900 - 10,100 = 37,800 \text{ lb toluene}$$

Calculation of T_1

heat exchanger:

$$(175 - 70) (0.45) (52,100) = 2,460,000 \text{ Btu above } 70^\circ\text{F}$$

$$(75 - 70) (0.45) (52,100) = 117,000 \text{ Btu in exit } \Delta H \text{ from tower 1}$$

$$\text{heat lost} = 2,460,000 - 117,000 = 2,343,000 \text{ Btu}$$

$$\text{temp. rise} = 2,343,000/(0.46) (100,000) = 50.6^\circ\text{F}$$

(continued)

$$T_1 = 70 + 50.6 = 120.6^\circ\text{F}$$

b₁. Tower 1:

$$\Delta H \text{ content of stream: } (100,000) (0.46) (185 - 70) = 4,830,000$$

$$\Delta H \text{ of reflux: } (6) (2,460,000) = \underline{14,740,000}$$

$$\Delta H \text{ in (Btu)} = \underline{\underline{19,570,000}}$$

$$\Delta H \text{ of residue: } (220 - 70) (0.48) (47,900) = 3,450,000$$

$$\Delta H \text{ of liquid: } (175 - 70) (7) (52,100) (0.45) = 17,240,000$$

$$\Delta H \text{ of vaporization: } (93.2) (1.8) (7) (52,100) = 61,400,000$$

$$\Delta H \text{ of vapor: } (0.285) (179 - 175) (7) (52,100) = \underline{417,000}$$

$$\Delta H \text{ out (Btu): } = \underline{\underline{82,507,000}}$$

ΔH supplied by reboiler in tower 1:

$$82,507,000 - 19,570,000 = 62,937,000 \text{ Btu}$$

b₂. Tower 2

$$\text{In: charge} = 3,450,000$$

$$\text{Reflux: } (6) (37,800) (0.30) (230 - 70) = \underline{10,880,000}$$

$$\text{ht. in: (Btu)} = \underline{\underline{14,330,000}}$$

$$\begin{aligned} \text{Water used} &= 212,000 + 352,000 + 33,200 + 3550 \\ &= 600,750 \text{ gal/day} \end{aligned}$$

d. Heat Balance on Tower 1:

$$\text{charge: } 4,830,000 \quad \text{cond: } 61,857,000$$

$$\text{steam: } 62,937,000 \quad \text{Bz + tol: } 2,460,000$$

$$\text{residue: } \underline{3,450,000}$$

$$\text{total (Btu): } 67,767,000 = \underline{\underline{67,767,000}}$$

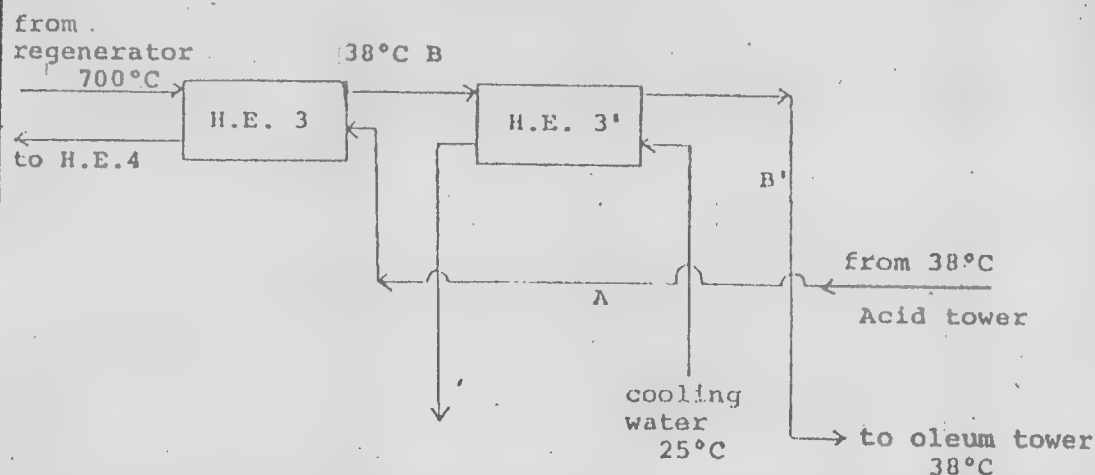
6.22

An important question to consider before attempting to solve the material and energy balances in a process is the feasibility of the flow sheet. The specified variables and data must contain enough information to solve the mass and energy balances written for the components of the flow sheet, and in particular must not overspecify or underspecify the problem as whole or for any component by providing more or fewer known state variables than there are design equations. If the flow sheet contains recycle streams, verification of the necessary data can become quite involved.

The feasibility of the flow sheet itself is not determined solely by the given data and the energy and material balances of the system. One must examine the flow sheet to make sure that a solution is technically feasible, i.e., will the flow sheet produce the desired results or has something been overlooked (ignoring the fact that there are always problems in producing the desired results when actually building a process and trying to get it started.) Spotting mistakes is only partly an analytical process; it often requires familiarity with the units that make up the process and the materials that are being processed.

In the problem presented one major mistake is readily identified by examination of the flow sheet: Heat exchanger number three is overspecified. The incoming cold stream A and the exiting hot stream B cannot both be at the same temperature.

Another heat exchanger, using water as a coolant for B, is necessary.



A more critical view of the process must examine what the water vapor in the gas does in the SO_3 adsorption process. SO_3 and water form a sulfuric acid mist that is almost impossible to absorb and is highly corrosive. 97% H_2SO_4 is used as an absorbant in the acid tower precisely because it has an extremely low partial pressure of water vapor. Any acid mist formed would circulate through the process, not be absorbed, and corrode the equipment, eventually escaping with the cleaned stack gases, a more harmful pollutant than SO_2 alone. Thus one should be sure that no water can contact the SO_3 .

(continued)

Solutions - Chapter 6

Barring leaks, the only source of water to the process is the incoming stack gas which undoubtedly contains water vapor from the combustion process:

Basis: 100 kg coal kg mol H₂

$$(5.2 \text{ kg H}) \left(\frac{\text{kg mol H}_2}{2 \text{ kg H}} \right) = 2.6 \text{ kg mol H}_2$$

2.6 kg mol H₂ is equivalent to

$$2.6 \text{ kg mol H}_2\text{O} \left(\frac{18 \text{ kg}}{\text{kg mol}} \right) = 47 \text{ kg H}_2\text{O}/100 \text{ kg coal}$$

To check whether or not water vapor will be present in the stack gas, the weight fraction of the water vapor in the combustion gases can be assumed to be equivalent to the weight fraction of water vapor in saturated air at a given temperature, assuming the stack gas approximates air in composition. The total amount of stack gas per 100 kg of coal is:

Basis: 100 kg coal

$$76.6 \text{ kg C} \left(\frac{\text{kg mol}}{12 \text{ kg}} \right) = 6.4 \text{ kg mol C}$$

$$5.2 \text{ kg H} \left(\frac{\text{kg mol H}_2}{2 \text{ kg H}_2} \right) = 2.6 \text{ kg mol H}_2$$

$$6.2 \text{ kg O} \left(\frac{\text{kg mol O}_2}{32 \text{ kg O}_2} \right) = 0.19 \text{ kg mol O}_2$$

$$2.3 \text{ kg S} \left(\frac{\text{kg mol}}{32 \text{ kg}} \right) = 0.072 \text{ kg mol S}$$

N and ash do not burn so that there is 90 kg of combusted material/100 kg coal.

Air required:

C + O ₂ + CO ₂	kg mol	
	6.4 C	
H ₂ + 1/2 O ₂ + H ₂ O	1/2(2.6) H ₂	
S + O ₂ + SO ₂	0.072 S	
	8.42	
	- 0.19 O ₂ in coal	
	8.23 mol O ₂ required from air	

$$\frac{8.23 \text{ kg mol O}_2}{0.21 \text{ kg mol O}_2} \left| \frac{1 \text{ kg mol air}}{1 \text{ kg mol air}} \right| \frac{29 \text{ kg air}}{1 \text{ kg mol air}} (1.18)$$

$$= 1340 \text{ kg dry air}$$

(continued)

$$\text{total weight of combustion gases} = 90 + 1340 = 1430 \text{ kg}$$

$$\text{weight fraction of water vapor} = \frac{47 \text{ kg}}{1430 \text{ kg}} = 0.033$$

Thus, the weight fraction of the water vapor is approximately 0.033, even assuming the air used for combustion is completely dry. Saturated air, even at 60°C, has a partial water pressure of 149.4 mm Hg. Then the weight fraction of water, assuming ideal gases is

$$\frac{P_{\text{H}_2\text{O}}}{P_{\text{air}}} = \frac{149.4 \text{ kg mol H}_2\text{O}}{(760 - 149.4) \text{ kg mol dry air}} \left| \frac{1 \text{ kg mol dry air}}{29 \text{ kg dry air}} \right|$$

$$\left| \frac{18 \text{ kg H}_2\text{O}}{1 \text{ kg mol H}_2\text{O}} \right| = \frac{0.15 \text{ kg H}_2\text{O}}{\text{kg air}}$$

Looking at the sorbent, the sorbent-air and stack gas streams will mix. Some water vapor will enter the Regenerator. If only 0.1% of the water vapor reaches the Regenerator

$$\frac{2.6 \text{ kg mol}}{100 \text{ kg coal}} \left| \frac{1 \text{ kg mol H}_2\text{O}}{1000 \text{ kg mol}} \right| \left| \frac{18 \text{ kg H}_2\text{O}}{1 \text{ kg mol H}_2\text{O}} \right| = \frac{4.7 \times 10^{-2} \text{ kg}}{100 \text{ kg coal}}$$

$$\frac{4.7 \times 10^{-2} \text{ kg H}_2\text{O}}{100 \text{ kg coal}} \left| \frac{2000 \text{ kg}}{1 \text{ metric ton}} \right| \left| \frac{340 \text{ metric ton coal}}{\text{hr}} \right|$$

$$= 320 \text{ kg H}_2\text{O/hr}$$

$\text{H}_2\text{O} + \text{SO}_3 \rightarrow \text{H}_2\text{SO}_4$, so that the equivalent sulfuric acid is

$$\frac{320 \text{ kg H}_2\text{O}}{18 \text{ kg/kg mol H}_2\text{O}} \left| \frac{1 \text{ kg mol H}_2\text{SO}_4}{1 \text{ kg mol H}_2\text{O}} \right| \left| \frac{98 \text{ kg H}_2\text{SO}_4}{1 \text{ kg mol H}_2\text{SO}_4} \right| = 1740 \frac{\text{kg H}_2\text{SO}_4}{\text{hr}}$$

Thus, the flow sheet is not feasible unless the water vapor can be eliminated from entering the absorber.

(continued)

6.23

a.	$(\text{NH}_4)_2\text{SO}_4$	(22)(500)	=	11,000
	Benzol	(15)(500)	=	7,500
	Toluol	(5)(500)	=	2,500
	Pyridine	(3)(500)	=	1,500
	Phenol	(5)(500)	=	2,500
	Naphthalene	(7)(500)	=	3,500
	Cresols	(20)(500)	=	10,000
	Pitch	(40)(500)	=	20,000
	Coke	(1500)(500)	=	750,000
	Gas	5,000,000 cu ft	=	199,670

$$\frac{34}{132} \times 11,000 = 2830 \text{ lb } \text{NH}_3 \text{ removed as } (\text{NH}_4)_2\text{SO}_4$$

$$\text{NH}_3 = \frac{36}{132} \times 22 \times 500 = 3000 \text{ lb}$$

b. Basis: $80^\circ\text{C} = 178^\circ\text{F}$ Primary towerHeat in

		$\times 10^{-6}$
Pitch	$20,000(.65)(475)$	= 6.83
Cresols	$10,000(.55)(219) + 181 + (.50)(104.2)$	= 3.54
Toluene	$2,500(.53)(54) + 155.9 + (.35)(471)$	= 0.87
Benzene	$7,500(.30)(525)$	= 1.18
Phenol	$2,500(.56)(183) + 162 + (.45)(342)$	= 1.05
Pyridine	$1,500(.41)(61.2) + 193.5 + (.28)(463.8)$	= 0.52
Naphthalene	$3,500(0.282)(0.4) + 64.05 + (.40)(247.7)$ $+ 136 + (.35)(277)$	= <u>1.39</u>
		16.38 Btu

Heat Out

Pitch	$20,000(.65)(475)$	= 6.18
Cresols	$10,000(.55)(219) + 181 + (.50)(104.2)$	= 3.54
Toluene	$2,500(.53)(54) + 155.9 + (.35)(70.1)$	= 0.52
Benzene	$7,500(.30)(124.1)$	= 0.28
Phenol	$2,500(.56)(183.6) + 162 + (.45)(41.4)$	= 0.71
Pyridine	$1,500(.41)(61.1) + 193.2 + (.28)(163.9)$	= 0.40
Naphthalene	$3,500(.282)(0.36) + 64.05 + (.40)(225)$	= <u>0.54</u>
		12.17 Btu

$$(16.38 - 12.17) \times 10^6 = 4.21 \times 10^6 \text{ Btu lost in primary tower}$$

Secondary tower

<u>Out</u>		$\times 10^{-6}$
Benzene	0	0.00
Toluene	$2,500(.53)(54) + 155.1 + (.35)(21.6)$	$\frac{0.48}{0.48 \text{ Btu}}$

<u>In</u>		$\times 10^{-6}$
Benzene	0.28	
Toluene	$\frac{0.52}{0.80 \text{ Btu}}$	$\therefore \text{Loss} = (0.80 - 0.48) \times 10^{-6}$ $= 0.32 \times 10^{-6} \text{ Btu}$

c. 2500 lb Phenol

$$\frac{2500}{94} = 26.6 \text{ lb mol}$$

94

26.6 lb mol NaOH (100% solution)

$$\frac{26.6 \times 40}{H} = 2660 \text{ lb 40\% NaOH required}$$

d. $\text{C}_5\text{H}_5\text{N}$ (MW = 79)

$$\frac{(1500)(98)}{(79)(.5)} = 3720 \text{ lb 50\% H}_2\text{SO}_4$$

e. Pyridine: $\text{H}_2\text{SO}_4 + 2 \text{ NaOH} + \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} + \text{Pyridine}$

$$\left(\frac{1860}{98}\right)(142) = 2700 \text{ lb Na}_2\text{SO}_4$$

$$\text{Phenol} = (13.3)(142) = 1890 \text{ lb}$$

$$\text{Total Na}_2\text{SO}_4 = 4590 \text{ lb}$$

f. $(10,000)(500) = 5,000,000 \text{ cu ft}$

$$(500)(2000)(300) = 300,000,000 \text{ Btu}$$

$$\frac{300,000,000}{555} = 540,000 \text{ cu ft}$$

$$\% \text{ gas needed } \frac{541,000}{500,000,000} = 10.8\%$$

6.24

COM1 (GCOMP) INLET = FEED OUTLET =
 S001
 OUTLET PRESSURE, PSIA = 100.00 OUTLET TEMP, DEG F = 282.22
 ISENTROPIC TEMP, DEG F = 324.40 ISENTROPIC HORSEPOWER = 276.2
 INDICATED HORSEPOWER = 223.6 BRAKE HORSEPOWER = 279.5
 DISPLACEMENT, CFH = 98957.1 VOLUMETRIC EFFICIENCY = .8912

HEAT -HEATR -INLET = S001, OUTLET =
 S002
 OUTLET TEMP = 100.00 DEG F, PRESSURE DROP = 2.00 PSI
 DUTY = -.5683E+06 BTU/HR

COM2 (GCOMP) INLET = S002 OUTLET = OUT
 OUTLET PRESSURE, PSIA = 569.00 OUTLET TEMP, DEG F = 382.02
 ISENTROPIC TEMP, DEG F = 453.14 ISENTROPIC HORSEPOWER = 441.0
 INDICATED HORSEPOWER = 351.3 BRAKE HORSEPOWER = 439.1
 DISPLACEMENT, CFH = 33777.4 VOLUMETRIC EFFICIENCY = .8013

STREAM NAME:	FEED	OUT	S001	S002
	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 HYDROGEN	418.000	418.000	418.000	418.000
2 METHANE	22.0000	22.0000	22.0000	22.0000
TOTAL LBMOL/HR	440.000	440.000	440.000	440.000
TOTAL LB/HR	1195.61	1195.61	1195.61	1195.61
1000 BTU/HR	301.37	1195.92	870.34	302.06
DEGREES F	100.00	382.02	282.22	100.00
PSIA	30.000	569.000	100.000	98.000
DENSITY, LB/FT3	.0136	.1684	.0340	.0442
MOLE FRAC VAPOR	1.0000	1.0000	1.0000	1.0000

Solutions - Chapter 6

6.25

50% Recycle

STREAM NAME:	BOTM	FEED	OVHD	PROD	RECY
	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 METHANE	.03163	3.11682	3.10100	.01582	.01581
2 ETHANE	.21331	3.32579	3.21911	.10666	.10663
3 PROPANE	3.51170	15.8752	14.1188	1.75585	1.75531
4 N-BUTANE	10.8815	15.0000	9.55772	5.44074	5.43919
5 ISO-BUTENE	13.1508	21.0000	14.4230	6.57538	6.57376
6 1,3-BUTADIENE	63.4611	95.0000	63.2610	31.7305	31.7a21
TOTAL LBMOL/HR	91.2500	153.318	107.681	45.6250	45.6128
TOTAL LB/HR	4964.56	8038.45	5555.51	2482.28	2481.62
1000 BTU/HR	-794.83	509.26	64.43	-397.42	-397.31
DEGREES F	41.00	185.00	41.00	41.00	41.00
PSIA	25.000	100.000	25.000	25.000	100.000
DENSITY, LB/FT3	38.9928	.8313	.2504	38.9928	38.9929
MOLE FRAC VAPOR	0.0000	1.0000	1.0000	0.0000	0.0000

STREAM NAME:	S001	S002	S003
	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 METHANE	3.13263	.01582	.01582
2 ETHANE	3.43242	.10666	.10666
3 PROPANE	17.6305	1.75585	1.75585
4 N-BUTANE	20.4392	5.44074	5.44074
5 ISO-BUTENE	27.5738	6.57538	6.57538
6 1,3-BUTADIENE	126.722	31.7305	31.7305
TOTAL LBMOL/HR	198.931	45.6250	45.6250
TOTAL LB/HR	10520.1	2482.28	2482.28
1000 BTU/HR	111.95	-397.42	-397.42
DEGREES F	126.20	41.00	41.00
PSIA	100.000	25.000	100.000
DENSITY, LB/FT3	0.0000	38.9928	38.9928
MOLE FRAC VAPOR	.8232	0.0000	0.0000

(continued)

25% Recycle

Solutions - Chapter 6

STREAM NAME:	BOIM	FEED	OVHD	PROD	RECY
	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 METHANE	.02109	3.11682	3.10100	.01582	.00527
2 ETHANE	.14225	3.32579	3.21911	.10668	.03556
3 PROPANE	2.34175	15.8752	14.1189	1.75631	.58543
4 N-BUTANE	7.25626	15.0000	9.55780	5.44219	1.81406
5 ISO-BUTENE	3.75941	21.0000	14.4229	6.57705	2.10000
6 1,3-BUTADIENE	42.3114	95.0000	63.2612	31.7388	10.5796
TOTAL LBMOL/HR	60.8492	153.318	107.681	45.6369	15.2123
TOTAL LB/HR	3310.57	8038.45	5555.52	2482.93	827.642
1000 BTU/HR	-530.03	509.26	64.43	-397.52	-132.51
DEGREES F	41.00	185.00	41.00	41.00	41.00
PSIA	25.000	100.000	25.000	25.000	100.000
DENSITY, LB/FT3	38.9928	.8313	.2504	38.9928	38.9928
MOLE FRAC VAPOR	0.0000	1.0000	1.0000	0.0000	0.0000

STREAM NAME:	S001	S002	S003
	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 METHANE	3.12209	.00527	.00527
2 ETHANE	3.36136	.03556	.03556
3 PROPANE	16.4606	.58544	.58544
4 N-BUTANE	16.8141	1.81406	1.81406
5 ISO-BUTENE	23.1924	2.19235	2.19235
6 1,3-BUTADIENE	105.580	10.5796	10.5796
TOTAL LBMOL/HR	168.530	15.2123	15.2123
TOTAL LB/HR	8866.09	827.643	827.643
1000 BTU/HR	376.75	-132.51	-132.51
DEGREES F	137.17	41.00	41.00
PSIA	100.000	25.000	100.000
DENSITY, LB/FT3	.9260	38.9928	38.9928
MOLE FBAC VAPOR	1.0000	0.0000	0.0000

No Recycle

STREAM RECY IS ZERO

STREAM S002 IS ZERO

STREAM S003 IS ZERO

STREAM NAME:	BOIM	FEED	OVHD	PROD	RECY
	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR	LBMOL/HR
1 METHANE	.01582	3.11682	3.10100	.01582	3.11682
2 ETHANE	.10668	3.32579	3.21911	.10668	3.32579
3 PROPANE	1.75631	15.8752	14.1189	1.75631	15.8752
4 N-BUTANE	5.44219	15.0000	9.55781	5.44219	15.0000
5 ISO-BUTENE	6.57705	21.0000	14.4229	6.57705	21.0000
6 1,3-BUTADIENE	31.7388	95.0000	63.2612	31.7388	95.0000
TOTAL LBMOL/HR	45.6369	153.318	107.681	45.6364	153.318
TOTAL LB/HR	2482.93	8038.45	5555.52	2482.93	8038.45
1000 BTU/HR	-397.52	509.26	64.43	-397.52	509.26
DEGREES F	41.00	185.00	41.00	41.00	185.00
PSIA	25.000	100.000	25.000	25.000	100.000
DENSITY, LB/FT3	38.9928	.8313	.2504	38.9928	.8313
MOLE FRAC VAPOR	0.0000	1.0000	1.0000	0.0000	1.0000

(continued)

Solutions - Chapter 6

6.26

STREAM COMPONENT FLOW RATES - KG MOLS/AIR

STREAM ID	1	2	3	4	5	6
NAME	INLET GAS					
PHASE	MIXED	VAPOR	VAPOR	VAPOR	LIQUID	MIXED
1 NITROGEN	181.0000	179.6106	179.6156	179.7345	0.0087	179.7345
2 CO2	1920.0000	1827.1284	1827.1284	1832.9626	0.5458	1832.9626
3 METHANE	14515.0000	14117.3906	14117.3906	14143.7344	2.3537	14143.7344
4 ETHANE	9072.0000	8010.3682	3010.3682	8064.8525	5.8165	8064.8525
5 PROPANE	7260.0000	5138.6318	5138.6318	5228.9082	10.8500	5228.9082
6 BUTANE	770.0000	399.4697	399.4697	413.3093	1.7963	413.3092
7 BUTANE	2810.0000	1229.4946	1229.4946	1285.9678	7.6706	1285.9675
8 PENTANE	951.0000	239.5409	239.5409	262.0803	3.3762	262.0803
9 PENTANE	1633.0000	339.8380	339.8380	379.3123	6.1499	379.3123
10 HEXANE	1542.0000	129.1421	129.1421	165.9431	7.0540	165.9431
11 BP135	11975.0000	93.9453	93.9453	154.5959	65.6602	154.5959
12 BP260	9072.0000	0.2617	0.2617	0.0036	0.2616	0.0036
13 BP500	9072.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTALS	70775.0000	31704.8047	31704.8047	32111.3828	111.5435	32111.3828
TEMPERATURE, DEG C	45.0000	45.0051	60.0000	55.7191	55.7191	60.0000
PRESSURE, KPA	450.0000	450.0000	1100.0000	1100.0000	1100.0000	2600.0000
11 MM KJ /HR	462.6024	330.9030	349.0496	351.7608	0.6275	332.5598
MOLE FRACT LIQUID	0.5522	0.0000	0.0000	0.0000	1.0000	0.0080
RECYCLE CONVERGENCE	0.0000	0.0000	0.0000	0.0000	-0.0060	0.0000
STREAM ID	7	8	9	10	11	12
NAME				COMPR VAPOR		CONDENSATE
PHASE	VAPOR	LIQUID	MIXED	VAPOR	LIQUID	LIQUID
1 NITROGEN	180.7536	0.1279	180.7536	179.6042	1.1493	1.3931
2 CO2	1858.4001	6.3981	1858.4001	1826.5083	31.8919	93.4211
3 METHANE	14283.7637	28.7751	14283.7637	14114.6504	169.1123	399.9786
4 ETHANE	8223.9980	60.4689	8223.9980	8004.0049	219.9934	1067.4871
5 PROPANE	5386.3184	101.4202	5386.3174	5127.0469	259.2706	2132.2896
6 BUTANE	428.6809	15.6834	428.6808	397.5724	31.1084	372.3384
7 BUTANE	1335.0337	64.3417	1335.0334	1221.4304	113.6030	1588.2261
8 PENTANE	270.5154	26.0022	270.5154	236.0146	34.5007	716.8571
9 PENTANE	388.9042	45.7813	388.9041	333.4250	55.4790	1299.3508
10 HEXANE	157.5544	44.0534	157.5544	121.7904	35.7641	1419.9502
11 BP135	58.9876	126.3875	58.9876	28.7576	30.7300	11947.1621
12 BP260	0.0000	0.0036	0.0000	0.0000	0.0000	9071.9930
13 BP500	0.0000	0.0000	0.0000	0.0000	0.0000	9072.0000
TOTALS	32572.8906	519.4429	32572.8906	31590.2891	982.6025	39182.4453
TEMPERATURE, DEG C	57.0695	57.0695	60.0000	60.0000	60.0000	45.0051
PRESSURE, KPA	2600.0000	2600.0000	6200.0000	6200.0000	6200.0000	450.0000
11 MM KJ /HR	335.5528	3.3357	270.3684	264.0405	6.3286	132.4387
MOLE FRACT LIQUID	0.0000	1.0000	0.0302	0.0000	1.0000	1.0000
RECYCLE CONVERGENCE	0.0000	0.0045	0.0000	0.0000	0.0028	0.0000

Heat duty:

Exchanger No.	Q (MM kJ/hr)	Temp. (°C)	Press. (kPa)
1	82.04	60	1100
2	120.33	60	2600
3	165.35	60	6200

Solutions - Chapter 6

6.27

STREAM ID NAME PHASE	1 INLET GAS VAPOR	2 MIXED	3 MIXED	4 VAPOR	5 LIQUID	6 MIXED
1 NITROGEN	211.9104	211.9104	211.9104	198.0745	13.8359	13.8359
2 METHANE	1957.0227	1957.0227	1510.3052	446.7177	1957.0227	446.7177
3 ETHANE	205.7486	205.7486	205.7486	55.7909	149.9577	149.9577
4 PROPANE	152.4361	152.4361	152.4361	10.6024	141.8337	141.8337
5 BUTANE	26.5223	26.5223	26.5223	0.6496	25.8727	25.8727
6 PENTANE	65.3680	65.3680	65.3680	0.9780	64.3892	64.3892
7 HEXANE	18.4852	18.4852	18.4852	0.0892	18.3960	18.3960
8 HEPTANE	21.9679	21.9679	21.9679	0.0724	21.8956	21.8956
9 OCTANE	11.2519	11.2519	11.2519	0.0000	11.2433	11.2433
10 NONANE	8.3050	11.3050	11.3050	0.0014	8.3036	11.3036
TOTALS	2679.0156	2679.0156	1776.5720	902.4447	2679.0156	902.4445
TEMPERATURE, DEC F	120.0000	7.4668	-84.0000	-84.0000	-84.0000	-134.7104
PRESSURE, PSIG	588.0000	578.0000	573.0000	573.0000	573.0000	125.0000
HL MM BTU /HR	4.9855	-0.2978	-5.3106	-2.4487	-2.8619	-2.8619
MOLE FRACT LIQUID	0.0000	0.1135	0.3369	0.0000	1.0000	0.6545
RECYCLE CONVERGENCE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STREAM COMPONENT FLOW RATES - LD MOLS/HR						
STREAM ID NAME PHASE	7 MIXED	8 VAPOR	9 LIQUIDS	10 RESIDUE	11 VAPOR	12 MIXED
1 NITROGEN	198.0745	211.9109	0.0000	211.9109	211.9109	211.9104
2 METHANE	1510.3052	1952.8789	4.1493	1952.8789	1952.8789	1957.0227
3 ETHANE	55.7909	30.4285	175.3177	30.4285	30.4285	205.7485
4 PROPANE	10.6024	0.4553	151.9786	0.4553	0.4553	152.4361
5 BUTANE	0.6496	0.0040	26.5179	0.0040	0.0040	26.5221
6 PENTANE	0.9788	0.0025	65.3645	0.0025	0.0025	65.3600
7 HEXANE	0.0892	0.0000	18.4849	0.0000	0.0000	18.4852
8 HEPTANE	0.0724	0.0000	21.9676	0.0000	0.0000	21.9679
9 OCTANE	0.0086	0.0000	11.2517	0.0000	0.0000	11.2519
10 NONANE	0.0014	0.0000	8.3048	0.0000	0.0000	8.3050
TOTALS	1776.5720	2195.6792	483.3371	2195.6792	2195.6792	2679.0156
TEMPERATURE, DEC P	-174.6392	-170.2356	24.8966	110.0000	156.7539	-84.0000
PRESSURE, PSIC	125.0000	125.0000	125.0000	120.0000	160.4095	573.0000
HL MM BTU /HR	-3.4297	-3.7743	-0.1439	1.5090	2.3917	-53105
MOLE FRACT LIQUID	0.0622	0.0000	1.0000	0.0000	0.0000	0.3369
RECYCLE CONVERGENCE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(continued)

SUMMARY OF HEAT EXCHANGE UNITS

5 UNIT E1, GAS-GAS EX, IS A HEAT EXCHANGER

OPERATING CONDITIONS

DUTY, MM KJ /HR	5.57417
WEIGHTED LMTD, DEG K	30.087
F FACTOR	1.00000
MTD, DEG K	30.087
U * A, KJ /HR DEG K	185265.594

HOT SIDE CONDITIONS		INLET	OUTLET
FEED(S)		1	
MIXED PRODUCT			2
VAPOR,	KG MOL/HR	1215.1807	1077.3076
	M KGS/HR	27.3531	21.1992
	CP, KJ /KG - DEG K	2.2837	2.3829
LIQUID,	KG MOL/HR	0.0000	137.8730
	M KGS/HR	0.0000	6.1539
	CP, KJ /KG - DEG K	0.0000	2.3937
TOTAL,	KG MOL/HR	1215.1807	1215.1807
CONDENS VAPORIZATION, KG MOL/HR			137.8730
TEMPERATURE, DEG K		322.039	259.520
PRESSURE, KPA		4155.435	4086.487

COLD SIDE CONDITIONS		INLET	OUTLET
FEED(S)		8	
VAPOR PRODUCT			10
VAPOR,	KG MOL/HR	995.9431	995.9431
	M KGS/HR	17.3280	17.3280
	CP, KJ /KG - DEG K	2.1518	2.1288
LIQUID,	KG MOL/HR	0.0000	0.0000
	M KGS/HR	0.0000	0.0000
	CP, KJ /KG - DEG K	0.0000	0.0000
TOTAL,	KG MOL/HR	995.9431	995.9431
CONDENS(VAPORIZ)ATION, KG MOL/HR			0.0000
TEMPERATURE, DEG K		160.797	316.483
PRESSURE, KPA		963.168	928.694

HEAT EXCHANGER ZONE ANALYSIS

ZONE	DELTA T	AT COLD	LMTD,	DUTY		TOTAL DUTY
	INLET,	OUTLET,		MM KJ /HR	PERCENT	
	DEG K	DEG K	DEG K			MM KJ /HR
1	98.72	80.44	89.27	1.073	19.26	1.073
2	80.44	61.43	70.51	1.073	19.26	2.147
3	61.43	42.58	51.43	1.073	19.26	3.220
4	42.58	24.59	32.77	1.073	19.26	4.293
5	24.59	7.86	14.67	1.073	19.26	5.367
6	7.86	5.56	6.64	0.208	3.72	5.574

7.1



The amount of solution decreases at a rate of $15 - 10 = 5$ kg/min. By an overall balance, the amount of solution after t min is

$$(100 - 5t) \text{ kg}$$

Let χ = kg of salt per kg of solution in the tank after t min

$$\chi(0) = 0.60$$

Then $d\chi/dt$ = rate of change of the concentration in the tank. Salt balance at any time t

$$\text{Accumulation} = \text{In} - \text{Out}$$

$$(100 - 5t) \frac{d\chi}{dt} = (10)(0.1) - 15\chi$$

Separating variables

$$\frac{d\chi}{1 - 15\chi} = \frac{dt}{100 - 5t}$$

Integrating from 0 to 10 min

$$\int_{0.6}^{\chi} \frac{d\chi}{1 - 15\chi} = \int_0^{10} \frac{dt}{100 - 5t}$$

$$\ln \frac{(1 - 15\chi)}{(1 - 9)} = 3 \ln \frac{(100 - 50)}{100}$$

Solving: $\chi = 2/15$

$$\text{kg of solution after 10 min} = 100 - 50 = 50 \text{ kg}$$

$$\text{kg of salt in the tank} = (2/15)(50) = \boxed{6.67 \text{ kg}}$$

Solutions - Chapter - 7

- 7.2 Assume: (1) Ideal gas law applies
(2) Rate of inflow = rate of outflow

Propane balance: Accumulation = Input - Output

$$\left[\frac{x \text{ ft}^3 \text{ propane}}{\text{ft}^3 \text{ mixture}} \right]_{t+\Delta t} - \left[\frac{x \text{ ft}^3 \text{ propane}}{\text{ft}^3 \text{ mixture}} \right]_t (1500 \text{ ft}^3)$$

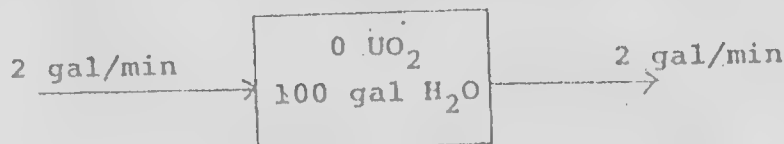
$$\begin{array}{c} \text{In} \\ \frac{0 \text{ ft}^3 \text{ propane}}{\text{ft}^3 \text{ mixture}} \left| \frac{30 \text{ ft}^3}{\text{min}} \right| \frac{\Delta t \text{ min}}{1} \end{array}$$

$$\begin{array}{c} \text{Out} \\ - \frac{x \text{ ft}^3 \text{ propane}}{\text{ft}^3 \text{ mixture}} \left| \frac{30 \text{ ft}^3}{\text{min}} \right| \frac{\Delta t \text{ min}}{1} \end{array}$$

$$1500 \int_1^{0.01} \frac{dx}{x} = -30 \int_0^t dt \rightarrow 1500 \ln x \Big|_1^{0.01} = -30 t \Big|_0^t$$

$$t = 230.5 \text{ min}$$

7.3



$$2 \text{ lb UO}_2 / 100 \text{ lb H}_2\text{O}$$

Ignore volume changes as the slurry concentration changes, and assume UO_2 in the H_2O does not change the density of the solution from that of water. The independent variable is $t = \text{time}$; dependent variable is $x = \text{lb UO}_2 \text{ in tank} / \text{lb H}_2\text{O}$ in tank.

$$\text{At } t = 0, x = 0$$

Material Balance on UO_2 in Δt :

$$\begin{array}{c} \text{In} \\ \frac{2 \text{ gal}}{\text{min}} \left| \frac{8.33 \text{ lb H}_2\text{O}}{\text{gal H}_2\text{O}} \right| \frac{2 \text{ lb UO}_2}{100 \text{ lb H}_2\text{O}} \left| \frac{\Delta t \text{ min}}{1} \right| \end{array}$$

(continued)

$$\frac{\text{Out}}{\text{min}} \left| \frac{2 \text{ gal}}{\text{min}} \left| \frac{8.33 \text{ lb H}_2\text{O}}{\text{gal H}_2\text{O}} \right| \frac{x \text{ lb UO}_2}{\text{lb H}_2\text{O}} \right| \Delta t \text{ min} =$$

$$\frac{\text{Accumulation}}{\text{lb H}_2\text{O}} \left| \frac{x \text{ lb UO}_2}{\text{lb H}_2\text{O}} \left| \frac{500 \text{ lb H}_2\text{O}}{\text{lb H}_2\text{O}} \right| \right|_{t+\Delta t} - \frac{x \text{ lb UO}_2}{\text{lb H}_2\text{O}} \left| \frac{500 \text{ lb H}_2\text{O}}{\text{lb H}_2\text{O}} \right|_t$$

$$\frac{(2)(8.33)}{(500)} \int_0^{60} dt = \int_0^x \frac{dx}{0.02 - x} = [-\ln[(0.02) - x]]_0^x$$

$$\boxed{x = 0.0173 \text{ lb UO}_2 / \text{lb H}_2\text{O}}$$

- 7.4 Assume: (1) Ideal gas law applies
(2) Rate of inflow = rate of outflow

O₂ balance: Accumulation = Input - Output

$$\left[\frac{x \text{ m}^3 \text{ O}_2}{\text{m}^3 \text{ mixture}} \right]_{t+\Delta t} - \frac{x \text{ m}^3 \text{ O}_2}{\text{m}^3 \text{ mixture}} \left| \left(\frac{94 \text{ m}^3 \text{ free vol}}{100 \text{ m}^3 \text{ reactor vol}} \right) \frac{200 \text{ m}^3}{\text{min}} \right|$$

$$= \frac{0 \text{ m}^3 \text{ O}_2}{\text{m}^3 \text{ mixture}} \left| \frac{20 \text{ m}^3}{\text{min}} \right| \Delta t \text{ min} - \frac{x \text{ m}^3 \text{ O}_2}{\text{m}^3 \text{ mixture}} \left| \frac{20 \text{ m}^3}{\text{min}} \right| \Delta t \text{ min}$$

$$188 \int_{0.210}^{0.001} \frac{dx}{x} = -20 \int_0^t dt \rightarrow 188 \ln x \Big|_{0.210}^{0.001} = -20 t \Big|_0^t$$

$$\boxed{t = 50.3 \text{ min}}$$

7.5 V₁ = initial volume

$$= (4/3) (\pi)^3 = (4/3) (\pi) (10)^3 = 4190 \text{ (ft)}^3$$

V₂ = final volume

$$= (4/3) (\pi) (9.5)^3 = 3590 \text{ (ft)}^3$$

(continued)

Solutions - Chapter - 7

(a) At constant pressure:

$$\frac{dV}{dt} = 5; \quad \int_{V_1}^{V_2} dV = 5 \int_0^t dt; \quad 5t = 4190 - 3590$$

$$\boxed{t = 120 \text{ min}}$$

(b) Assuming the rate of escaping is proportional to the volume and initially at $5(\text{ft})^3/\text{min}$.

$$\frac{dV}{dt} = KV; \quad 5 = KV_1 = 4190 K \text{ or } K = \frac{5}{4190}$$

$$\int_{V_1}^{V_2} \frac{dV}{V} = \frac{5}{4190} \int_0^t dt$$

$$t = \frac{4190}{5} \ln \left(\frac{V_2}{V_1} \right) = 858 \ln \frac{4190}{3590} = \boxed{131 \text{ min}}$$

(c) Not without another piece of information as the mass balance contains two unknowns, such a p and V .

7.6 ✓ Let the moisture content be w

$$\text{then, } \frac{dw}{dt} = kw$$

$$\int_{w_0}^{w_{0/2}} \frac{dw}{w} = k \int_0^{15} dt$$

$$\ln w \Big|_{w_0}^{w_{0/2}} = kt \Big|_0^{15} \quad \text{so} \quad k = 0.046 \text{ and } \int_{w_0}^w \frac{dw}{w} = k \int_0^t dt$$

$$\ln \frac{w}{w_0} = kt$$

$$\text{At } t = 15, w = w_{0/2}; k = \frac{\ln w_{0/2}}{15} = -0.463$$

(continued)

$$\ln \left(\frac{w}{w_0} \right) = -0.0463t$$

$$\text{When } w = 0.1 w_0, t = \frac{\ln \frac{0.1 w_0}{w_0}}{-0.0463} = \boxed{49.7 \text{ min}}$$

7.7

- a. Ignore friction, non-ideality at the discharge and the orifice coefficient and use instead

$$0.020 (2 + h^2) \text{ m}^3/\text{min}$$

$$\text{Vol cone} = \frac{1}{3} \pi r^2 h$$

$$\frac{r}{h} = \frac{3}{5}; r = \frac{3}{5} h \quad \therefore V = \frac{9}{75} \pi h^3$$

$$\frac{dV}{dt} = \frac{9}{25} \pi h^2 \frac{dh}{dt} = 1.13 h^2 \frac{dh}{dt} \frac{(\text{m})^3}{\text{min}}$$

$$= 0.020 (2 + h^2)$$

$$\int_{h_1}^{h_2} \frac{56.6 h^2 dh}{2 + h^2} = - \int_0^t dt = -t$$

$$t = -56.5 [h]_{h_1}^{h_2} + \left[\frac{113}{\sqrt{2}} \tan^{-1} \sqrt{2}h \right]_{h_1}^{h_2}$$

$$h_1 = 5 \text{ m} \quad h_2 = (3\sqrt{0.25}) h_1 = 3.15 \text{ m}$$

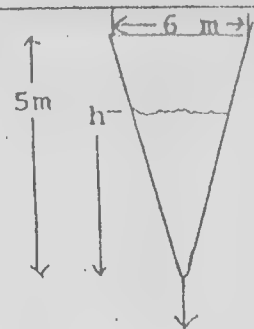
$$\therefore t = -56.6 (3.15 - 5) + 79.9 (\tan^{-1} 4.45 - \tan^{-1} 7.07)$$

$$\boxed{t = 98 \text{ min}}$$

- b. The rate of discharge at that time is:

$$\frac{dV}{dt} = 0.02 (2 + h^2)$$

$$= 0.02 (2 + (3.15)^2) = \boxed{0.24 \text{ m}^3/\text{min}}$$



(continued)

7.8 ✓
 20,000 gph
 0 lb organic

initially
 75,000 gal
 60,000 lb
 organic

15,000 gph
 x lb organic
 gal total

(1) Overall Balance:

Let y = total gal of mixture in the tank at time t (in hours)

$$\text{then } \frac{dy}{dt} = 20,000 - 15,000 = 5000$$

$$\int_{75,000}^y dy = 5000 \int_0^t dt$$

$$\therefore y = 5000(15 + t)$$

(2) Organic Material Balance:

Let x = $\frac{\text{lb. organic}}{\text{gal of mix}}$ in the tank at time t .

$$\text{Initially, } x = 60,000/75,000 = 0.8$$

Total amount of organic in the tank at time t is (yx) lbs.

Then the rate of accumulation of organic will be $d(yx)/dt$, lb/hr.

Rate Accumulation = Rate in - Rate out

$$\frac{d(yx)}{dt} = 0 - 15,000x$$

$$y \frac{dx}{dt} + x \frac{dy}{dt} = -15,000$$

$$\frac{dx}{dt} = \frac{-20,000x}{5000(15 + t)}$$

$$\int_{0.8}^x \frac{dx}{x} = -\int_0^t \frac{4dt}{15 + t}; \quad \ln \frac{x}{0.8} = -4 \ln \frac{15}{18}$$

$$x = 0.396$$

(continued)

The total wt of organic material in the tank after 3 hrs is:

$$yx = (75,000 + (5000)(3))(0.396) = \boxed{34,700 \text{ lbs}}$$

Alternative Solution:

If x = total lb of organic in the tank at any time t , then the concentration of organic is x/y .

The balance becomes:

$$\frac{dx}{dt} = - \frac{15,000 \text{ gal} \times \text{lb}}{\text{hr} \times y \text{ gal}}$$

$$\int_{60,000}^x \frac{dx}{x} = - \int_0^3 \frac{15,000 \text{ dt}}{5000 (15+t)}$$

$$\ln \frac{x}{60,000} = -3 \ln \frac{18}{15}$$

$$X = \boxed{34,700 \text{ lb organic}}$$

7.9



$$\text{Suspension Rate} = K(10-x) \text{ lb/hr}$$

- (1) Overall Balance: Assuming the sludge does not affect the volume of the mixture in the tank, the overall balance will be the same as that in Prob. 7.8, i.e. $y = 5000 (15+t)$ gal.
- (2) Organic Balance:

Let x = lb of organic in suspension per gal of total in the tank at time t in hours.

z = lb of sludge going into suspension at time t .

Rate of sludge going into suspension:

$$\frac{dz}{dt} = K(10-x)$$

$$@ x = 0 \quad y = 75,000 \text{ gal}$$

(continued)

$$\frac{dz}{dt} = \frac{0.05 \text{ lb}}{(\text{min})(\text{gal})} \left| \frac{75,000 \text{ gal}}{10} \right| \frac{60 \text{ min}}{\text{hr}} = K(10) \text{ lb/gal}$$

$$\text{Thus } K = \frac{(0.05)(75,000)(60)}{10} = 22,500 \text{ gal/hr}$$

$$\text{Rate of accumulation of organic: } \frac{d(yx)}{dt}$$

$$\text{Rate Acc.} = \text{Rate in} - \text{Rate out}$$

$$\frac{d(yx)}{dt} = [22,500(10-x)] - 15,000x$$

$$= y \frac{dx}{dt} + x \frac{dy}{dt}$$

$$\frac{dx}{dt} = \frac{45 - 8.5x}{15 + t}$$

$$\int_{0.8}^x \frac{dx}{5.3-x} = \int_0^3 \frac{8.5 \, dt}{15+t}; \quad -\ln \frac{5.3-x}{5.3-0.8} = 8.5 \ln \frac{18}{15}$$

$$\text{Solving, } x = 4.345 \text{ lb/gal}$$

$$\text{The total weight of organic in the tank after 3 hrs is } (90,000) (4.345)$$

$$= \boxed{391,050 \text{ lbs}}$$

Alternative Solution:

Let x = lb of organic in tank at time t

conc. = x/y , then

$$\frac{dx}{dt} = K(10 - x/y) - 15,000(x/y)$$

$$\frac{dx}{dt} + \frac{37,500x}{5000(15+t)} = 225,000$$

$$\frac{dx}{dt} + \frac{75x}{15+t} = 225,000; \quad \frac{d(15+t)^{7.5}x}{dt} = 225,000(15+t)^{7.5}$$

(continued)

$$(15+t)^{7.5} x = \left(\frac{225,000}{8.5} \right) (15+t)^{8.5} + C$$

$$x = 26,500(15+t) + C(15+t)^{-7.5}$$

$$\text{when } t = 0, x = 60,000, \text{ and } C = -338,000 (15)^{7.5}$$

$$\text{when } t = 3; x = 27,500 (18) - 338,000 (15/18)^{7.5}$$

$$x = 391,050 \text{ lb}$$

7.10 Let C, x, y = the number of moles of C, x , and y respectively at time t .

(1) C balance: $C_0 = 1$, initial moles of C

$$\frac{dC}{dt} = -kC; \quad \int_{C_0}^C \frac{dC}{C} = -k \int_0^t dt$$

$$\ln \frac{C}{C_0} = -kt; \quad C = C_0 e^{-kt} = e^{-kt}$$

(2) x balance:

$$\frac{dx}{dt} = kC = ke^{-kt}$$

$$\int_0^x dx = \int_0^t ke^{-kt} dt$$

$$x = 1 - e^{-kt}$$

$$e^{-kt} = 1 - e^{-kt} \quad \text{or} \quad 2e^{-kt} = 1$$

$$\ln 1/2 = -kt, \quad \text{or} \quad t = \frac{\ln 2}{k}$$

7.11 Mass balance:

Accumulation = Input - Output

$$d(\rho V) = 0 - [U_1 A_1 \rho dt + U_2 A_2 \rho dt]$$

$$\text{where } V = \pi(1^2)H \text{ m}^3, \quad A_1 = \pi(2.5)^2 \text{ cm}^2, \quad A_2 = \pi(5)^2 \text{ cm}^2$$

(continued)

$V = c\sqrt{2gh}$, $c = 0.61$, $g = 9.80 \text{ m/s}^2$ & $h = \text{height of H}_2\text{O level from orifice}$
 $H = \text{height of H}_2\text{O level from bottom}$
 $h_1 = H-1$ & $h_2 = H-0.5$

Assume ρ is constant. Then $dV = 9\pi dH$
 $= -0.61\sqrt{2 \times 9.80} (\pi \times 10^{-4}) \left[(6.25\sqrt{H-1} + 25\sqrt{H-0.5}) \right] dt$

$$-3.00 \times 10^{-5} \int_0^t dt = \int_{10}^5 \frac{dH}{6.25\sqrt{H-1} + 25\sqrt{H-0.5}}$$

$$-3.00 \times 10^{-5} t = \int_{10}^5 \frac{dH}{\sqrt{H-1} + 25\sqrt{H-0.5}} \times \frac{\sqrt{H-1} - 25\sqrt{H-0.5}}{\sqrt{H-1} - 25\sqrt{H-0.5}}$$

$$= \int_{10}^5 \left[\frac{\sqrt{H-1}}{\left(\frac{625}{2}-1\right)} - \frac{25\sqrt{H-0.5}}{\left(\frac{625}{2}-1\right) - 625H} \right] dH$$

Let $H-1 = x^2$ $H-0.5 = y^2$

$H = x^2 + 1$ $H = y^2 + 0.5$

$dH = 2x dx$ $dH = 2y dy$

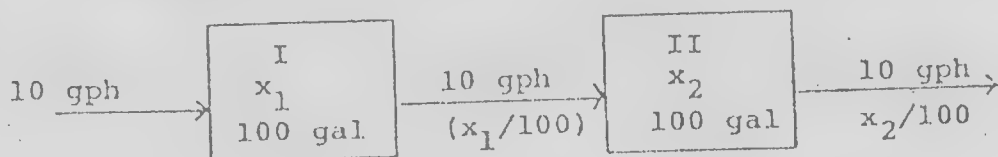
$$(-3.00) 10^{-5} t = \int \frac{x \cdot 2x \cdot dx}{\left(\frac{625}{2}-1\right) - 625(x^2+1)}$$

$$-25 \int \frac{y \cdot 2y \cdot dy}{\left(\frac{625}{2}-1\right) - 625(y^2+0.5)}$$

$t = 2.02 \times 10^3$

7.12

a.



Let x_1, x_2 be the number of lb of A in tank I or II at any time t respectively.

(continued)

A. Balance in tank I.

$$\frac{dx_1}{dt} = 0 - \left(\frac{10}{100}\right) x_1 = -0.1x$$

$$\int_{10}^x \frac{dx}{x} = -0.1 \int_0^t dt$$

$$x_1 = 10 e^{-0.1t}$$

$$\text{for } t = 3 \text{ hr; } x_1 = 10e^{-0.3} = 7.41 \text{ lb}$$

$$\text{Conc. of A in tank A} = \boxed{0.0741 \text{ lb/gal}}$$

b.

A Balance in tank II

$$\frac{dx_2}{dt} = 10\left(\frac{x_1}{100}\right) - 10\left(\frac{x_2}{100}\right)$$

$$\text{Since } x_1 = 10e^{-0.1t}$$

$$\frac{dx_2}{dt} = e^{-0.1t} - 0.1x_2$$

$$\frac{dx_2}{dt} + 0.1x_2 = e^{-0.1t}$$

$$(D + 0.1)x_2 = e^{-0.1t} \text{ where } D = d/dt$$

Particular integral

$$\text{P.I.} = e^{-0.1t}/D + 0.1 = (e^{-0.1t})/(D + 0.1 + 0.1)$$

$$= te^{-0.1t}$$

The general solution is

$$x_2 = Ce^{-0.1t} + te^{-0.1t}$$

$$\text{when } t = 0, x_2 = 10, \text{ and } C = 10$$

$$\therefore x_2 = e^{-0.3}(10 + 3) = 9.64 \text{ lb}$$

$$\text{Conc. of A in tank II} = \boxed{0.0964 \text{ lb / gal}}$$

(continued)

- 13 Assuming ρ to be constant, the material balance is as follows: Accumulation = inflow - outflow

$$\frac{dV}{dt} = Q_i - Q_o$$

$$= 2 - 0.01V$$

$$\left. \frac{dV}{dt} \right|_{t=0} = 1.5 \quad \boxed{V \text{ increases}}$$

$$\int_{50}^{100} \frac{dV}{2 - 0.01V} = \int_0^t dt$$

$$-\frac{1}{0.01} \ln(V - 200) \Big|_{50}^{100} = t \rightarrow \ln\left(\frac{100}{500}\right) = -0.01t$$

$$t = -100 \ln\left(\frac{100}{500}\right) = \boxed{40.6 \text{ min}}$$

- 14 Let x = mg of fission product in the tank at any time t ; when $t = 0$, $x = (10)(3.785)(10,000) = 3.785 \times 10^5$ mg

Rate of change = Rate in - Rate out - Rate decay

$$\frac{dx}{dt} = (10)(3.785)(100) - 100\left(\frac{x}{10,000}\right) - 0.01x$$

$$= 3785 - 0.02x$$

$$\int_{3.785 \times 10^5}^x \frac{dx}{3785 - 0.02x} = \int_0^{24} dt = 24$$

$$-\frac{1}{0.02} \ln(3785 - 0.02x) \Big|_{3.785 \times 10^5}^x = 24$$

$$x = 306,000 \text{ mg}$$

$\therefore$ conc. in the tank at the end of the first 24 hr =

$$30.6 \text{ mg/gal} \rightarrow \boxed{8.1 \text{ mg / liter}}$$

(continued)

b. $\frac{dx}{dt} = -0.01x$

$$\int_{306,000}^x \frac{dx}{x} = -0.01 \int_0^{24} dt$$

$$x = 30,600 e^{-0.24} = 241,000 \text{ mg}$$

$$\text{Conc} = \frac{241,000}{(10,000)(3.785)} = \boxed{6.4 \text{ mg / liter}}$$

c. The maximum conc. in the tank is $\boxed{10 \text{ mg / liter}}$

7.15 Basis: 1 day of operation 1440 min

Sr⁹² balance:

Let $x = \text{kg Sr}^{92} \text{ in tank per kg H}_2\text{O at time } t$

Accumulation = In - Out - Decay

$$\begin{aligned} x|_{t+\Delta t} - x|_t &= \frac{1.5 \times 10^{-3}}{\text{min}} \left| \frac{1.0 \times 10^3 \text{ kg H}_2\text{O}}{\text{m}^3} \right| \frac{1500 \text{ kg Sr}^{92}}{10^6 \text{ kg H}_2\text{O}} \Delta t \text{ min} \\ &\quad - \frac{1.5 \times 10^{-3} \text{ m}^3}{\text{min}} \left| \frac{1.0 \times 10^3 \text{ kg H}_2\text{O}}{\text{m}^3} \right| \frac{x \text{ kg Sr}^{92}}{\text{kg H}_2\text{O}} \Delta t \text{ min} \\ &\quad - \frac{0.693}{2.7} \left| \frac{1 \text{ hr}}{60 \text{ min}} \right| \frac{x \text{ kg Sr}^{92}}{\text{kg H}_2\text{O}} \Delta t \text{ min} \end{aligned}$$

$$\frac{dx}{dt} = (2.25)10^{-3} - 1.5(x) - 4.28 \cdot 10^{-3}(x)$$

Integrating between $t = 0$ and $t = 1440 \text{ min}$,

$$x = \boxed{1.5 \times 10^3 \text{ kg Sr}^{92} / \text{kg H}_2\text{O}}$$

Y⁹² balance:

Let $y = \text{lb Y}^{92} \text{ in tank per lb H}_2\text{O at time } t$

(continued)

$$\frac{dy}{dt} = (4.28)10^{-3}(x) - 1.5(y) - \frac{0.693y}{(3.5)(60)}, \text{ from which}$$

$$y = \boxed{4.28 \times 10^6 \text{ kg Y}^{92} / \text{kg H}_2\text{O}}$$

Zr⁹² balance:

Let z = lb Zr⁹² in tank per lb H₂O at time t

$$\frac{dz}{dt} = \frac{0.693}{(3.5)(60)} y - 1.5z, \text{ from which}$$

$$z = \boxed{9.39 \times 10^{11} \text{ kg Zr}^{92} / \text{kg H}_2\text{O}}$$

7.16 Assume isothermal process

Let $x = (\text{m}^3)$ in the tank at time t

$V = (\text{m}^3)/\text{min}$ entering and leaving the tank

Material balance on O₂ in terms of (m³) at $T, 1 \text{ atm}$

In	Out
$\frac{0.21(\text{m}^3)}{(\text{m}^3) \text{ air}} \left \frac{V(\text{m}^3)}{\text{min}} \right \Delta t, \text{ min}$	$\frac{x(\text{m}^3) \text{ O}_2}{3(\text{m}^3) \text{ gas}} \left \frac{V(\text{m}^3)}{\text{min}} \right \Delta t$

$$\begin{aligned} &\text{Accumulation} \\ &= x(\text{m}^3) \Big|_{t+\Delta t} - x(\text{m}^3) \Big|_t \end{aligned}$$

$$\int_3^x \frac{dx}{(0.21 - x/3)} = \int_0^t V dt = 9(\text{m}^3)$$

$$-3 \ln \frac{(0.21 - x/3)}{0.21 - 1} = 9$$

$$\therefore x = 0.75 (\text{m}^3)$$

$$\text{concentration} = \frac{0.75(\text{m}^3)}{3(\text{m}^3)} = 0.25$$

$$\text{or concentration} = \boxed{25\%}$$

(continued)

Solutions - Chapter - 7

7.17 Basis: 1 mol C_6H_{12}

$$\frac{d(C_4H_8)}{dt} = K(C_6H_{12}) \quad C_6H_{12} = 1 - C_4H_8$$

$$C_6H_{12} = 1 - C_2H_4$$

$$\frac{d(C_2H_4)}{dt} = K(C_6H_{12}) \quad \frac{d(C_6H_{12})}{dt} = -K(C_6H_{12})$$

$$C_6H_{12} = e^{-Kt}$$

7.18



$$T = 70^\circ F$$

Let p_1, n_1 = pressure and number of moles of N_2 in the large tank at any time t
 p_2, n_2 = the corresponding values in the small tank.

$$\text{Then, } \frac{dn_2}{dt} = K(p_1 - p_2)$$

$$\text{Initially } p_1 = 700, p_2 = 0; \frac{dn_2}{dt} = 0.2 \text{ kg mol/hr}$$

$$0.2 = K(700 - 0) \text{ or } K = 2.857 \times 10^{-4} \text{ kg mol/(hr)(kPa)}$$

Initially, no. of moles is

$$n_1^0 = \frac{30 \text{ m}^3}{22.4 \text{ m}^3} \left| \frac{700 \text{ kPa}}{101.3 \text{ kPa}} \right| \left| \frac{273 \text{ K}}{293 \text{ K}} \right| = 8.62 \text{ kg mol}$$

Assume ideal gas law holds.

$$pV = nRT$$

$$p_1 = \frac{8.31 \text{ (kPa)(m}^3)}{(K)(\text{kg mol})} \left| \frac{293 \text{ K}}{30 \text{ m}^3} \right| n_1 = 81.2 n_1$$

(continued)

$$P_2 = \frac{8.31 \text{ (kJ/mol}\cdot\text{K)}(m^3)}{(K)(kg \text{ mol})} \left| \frac{293 \text{ K}}{15 \text{ m}^3} \right| n_1 = 162.3 \text{ } n_2$$

$$n_1 + n_2 = 8.62$$

$$\frac{dn_2}{dt} = 2.857 \times 10^{-4} (700 - 81.2 \text{ } n_2)$$

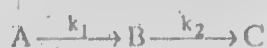
Final moles in tank 2 will be $(15/30+15) (8.62) = 2.87$ hence

$$1/2 (2.87) = 1.44.$$

$$\int_0^{1.44} \frac{dn_2}{700 - 81.2 \text{ } n_2} = 2.857 \times 10^{-4} \int_0^t dt$$

$$t = \boxed{27.5 \text{ hr}}$$

7.19



Initial conditions: at $t = 0$, $C_A = C_{AO}$ and $C_B = C_C = 0$

$$\frac{dC_A}{dt} = -k_1 C_A \quad (1)$$

$$\frac{dC_B}{dt} = -k_1 C_A - k_2 C_B \quad (2)$$

$$\frac{dC_C}{dt} = k_2 C_B \quad (3)$$

Simultaneous

From Eq. (1),

$$\frac{dC_A}{C_A} = -k_1 dt; \quad \int_{C_{AO}}^{C_A} \frac{dC_A}{C_A} = -k_1 \int_0^t dt, \text{ or } \ln \frac{C_A}{C_{AO}} = -k_1 t$$

$$\boxed{C_A = C_{AO} e^{-k_1 t}} \quad (4)$$

$$\frac{dC_B}{dt} = k_1 C_A - k_2 C_B = k_1 C_{AO} e^{-k_1 t} - k_2 C_B$$

(continued)

$$\frac{dC_B}{dt} + k_2 C_B = k_1 C_{AO} e^{-k_1 t} \quad (5)$$

which is the first-order linear differential equation of the form $dy/dx + Py = Q$.

By multiplying through with the integrating factor $e^{\int p dx}$, the solution is

$$ye^{\int p dx} = \int Qe^{\int p dx} dx + \text{constant}$$

Applying this general procedure to the integration of Eq. (5), we find that the integrating factor is $e^{k_2 t}$. The constant of integration is found to be $-k_1 C_{AO}/(k_2 - k_1)$ from the initial condition $C_{BO} = 0$ at $t = 0$, and the final expression for the variation in concentration of B is

$$C_B = C_{AO} k_1 \left(\frac{e^{-k_1 t}}{k_2 - k_1} + \frac{e^{-k_2 t}}{k_1 - k_2} \right) \quad (6)$$

If k_1 is much larger than k_2 , then

$$C_B = C_{AO} e^{-k_2 t} \quad (7)$$

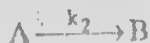
In other words, the concentration of B is determined by k_2 . Noting that for the constant-volume system there is no net change in total number of moles, we find the material balance at any time to be

$$C_{AO} = C_A + C_B + C_C$$

which with Eqs. (4) and (5) gives

$$C_C = C_{AO} \left(1 + \frac{k_2}{k_1 - k_2} e^{-k_1 t} + \frac{k_1}{k_2 - k_1} e^{-k_2 t} \right) \quad (8)$$

7.20

Simultaneous

$$\frac{dC_A}{dt} = -k_2 C_A + k_1 C_B - k_3 C_A = -(k_2 + k_3) C_A + k_1 C_B \quad (1)$$

(continued)

$$\frac{dC_B}{dt} = k_2 C_A - k_1 C_B \quad (2)$$

$$\frac{dC_C}{dt} = k_3 C_A \quad (3)$$

Initial conditions: at $t = 0$, $C_A = C_{AO}$ and $C_B = C_C = 0$.

To solve Eqs. (1) - (3) use matrix operations

$$Q = \begin{bmatrix} -(k_2 + k_3) & k_2 \\ k_1 & -k_1 \end{bmatrix}$$

$$C^T = [C_A, C_B] \quad C(0)^T = [C_{AO}, 0]$$

To find the eigenvalues of Q we set

$$|Q - \lambda I| = \begin{vmatrix} -(k_2 + k_3) - \lambda & k_2 \\ k_1 & -k_1 - \lambda \end{vmatrix} = (k_2 + k_3 + \lambda)(k_1 + \lambda) - k_2 k_1 = 0$$

The roots are

$$\lambda_1 = \frac{-a + \sqrt{a^2 - 4k_2 k_3}}{2}$$

$$\lambda_2 = \frac{-a - \sqrt{a^2 - 4k_2 k_3}}{2}$$

where: $a = (k_1 + k_2 + k_3)$. Consequently the solution to the set of Eqs. (1) and (2) is:

$$C^T = [C_{AO}, 0] \left[\frac{Q - \lambda_2 I}{\lambda_1 - \lambda_2} e^{\lambda_1 t} + \frac{Q - \lambda_1 I}{\lambda_2 - \lambda_1} e^{\lambda_2 t} \right]$$

$$[C_A, C_B] = \frac{1}{d} [-C_{AO}(k_1 + k_3 + \lambda_2), C_{AO}k_1] - \frac{1}{d} [-C_{AO}(k_1 + k_3 + \lambda_1), C_{AO}k_1] \times e^{\lambda_1 t}$$

where: $d = \lambda_1 - \lambda_2$. Finally,

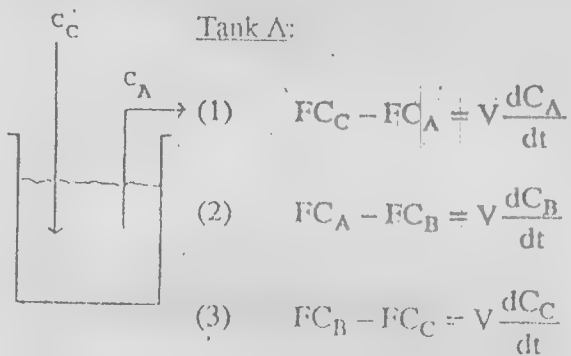
(continued)

$$C_A = \frac{C_{AO}}{\sqrt{(k_1 + k_2 + k_3)^2 - 4k_2k_3}} \left[-(k_1 + k_3 + \lambda_2)e^{\lambda_1 t} + (k_1 + k_3 + \lambda_1)e^{\lambda_2 t} \right] \quad (4)$$

$$C_B = \frac{C_{AO}k_1}{\sqrt{(k_1 + k_2 + k_3)^2 - 4k_2k_3}} \left[e^{\lambda_1 t} - e^{\lambda_2 t} \right] \quad (5)$$

$$C_C = \frac{C_{AO}k_3}{\sqrt{(k_1 + k_2 + k_3)^2 - 4k_2k_3}} \left[-(k_1 + k_3 + \lambda_2) \frac{e^{\lambda_1 t}}{\lambda_1} + (k_1 + k_3 + \lambda_1) \times \frac{e^{\lambda_2 t}}{\lambda_2} \right] \quad (6)$$

7.21



$$F[=] \frac{\text{gal}}{\text{min}} = 50$$

$$V[=] \text{gal} = 1000$$

$$C[=] \frac{\text{lb}}{\text{gal}}$$

$$\Delta = \begin{bmatrix} -50 & 50 & 0 \\ 0 & -50 & 50 \\ 50 & 0 & -50 \end{bmatrix}$$

$$\underline{Y}^T = [C_A, C_B, C_C], \quad \underline{Y}^T(0) = [3, 0, 3]$$

$$\Delta - \lambda I = \begin{bmatrix} -50 - \lambda & 50 & 0 \\ 0 & -50 - \lambda & 50 \\ 50 & 0 & -50 - \lambda \end{bmatrix} = 0$$

(continued)

$$0 = -(50 + \lambda)^3 + (50)^3$$

$$0 = (50)^3 - 3(50)^2 \lambda - 150\lambda^2 - \lambda^3 + (50)^3$$

$$0 = \lambda[3(50)^2 + (150)\lambda^2 - \lambda^3 + (50)^3]$$

roots: $\lambda_1 = 0$

$$\lambda_{2,3} = \frac{-150 \pm \sqrt{22,500 - 30,000}}{2}$$

when $t = 0$, $C_A V = 3000$ lb, $C_C V = 3000$, $C_B V = 0$

$t_A = ?$, $C_A V = 2100$ lb; $t_C = ?$, $C_C V = 2100$ lb; $t_B = ?$,

$C_B V = 1900$ lb.

Solve the equations to get $t_A = 22.8$ min, $t_C = \boxed{28.2 \text{ min}}$,

$t_B = 24.4$ min

Energy balance around the tank:

7.22

$$\frac{dU_T}{dt} = -\Delta(\hat{H}m) \quad (1)$$

Energy balance around the heat exchangers:

$$0 = \frac{dE_{II}}{dt} = \frac{dU_{II}}{dt} = -\Delta(\hat{H}m) + Q \quad (2)$$

We have assumed that the residence time of the liquid in the heat exchanger is very small and that kinetic and potential energy contributions are negligible. From Eqs. 1 and 2 we obtain

$$\frac{dU_T}{dt} = -Q \quad (3)$$

Subscripts T and II refer to the tank and the heat exchanger, respectively. Because the liquid is approximately incompressible, $C_p \equiv C_v$. Then, $dU_T = mC_v dT \equiv mC_p dT$. Furthermore, the rate of heat addition to the liquid Q is given by $Q = U_o A_o (T - 180^\circ)$. The notation used here is the same as the one introduced in Problem 7.24. Hence, Eq. 3 becomes

$$mC_p \frac{dT}{dt} = -U_o A_o (T - 180) \quad (4)$$

(continued)

$$\frac{dT}{dt} + \frac{U_o A_o}{mC_p} T = 180 \frac{U_o A_o}{mC_p} \quad (5)$$

Eq. 5 is a first-order linear differential equation. Its solution is

$$T \exp\left(\frac{U_o A_o}{mC_p} t\right) = 180 \frac{U_o A_o}{mC_p} \quad (6)$$

From the initial condition, $T = 60^\circ\text{F}$ at $t = 0$, the value of the constant is this: constant $= -120^\circ\text{F}$. From Eq. 6, the expression for t is

$$t = \frac{mC_p}{U_o A_o} \ln\left(\frac{120}{180 - 120}\right) = \quad (7)$$

For the data given,

$$t = \frac{(10,000)(1.0)}{(40)(300)} \ln\left(\frac{120}{180 - 120}\right) = \boxed{0.578 \text{ hr}}$$

7.23 a. We shall make the following assumptions:

1. Steam temperature remains constant in coil.
2. Heat capacity of suspension does not change very much with change in temperature.
3. Agitator maintains uniform temperature throughout.
4. Heat-transfer coefficient is independent of position and time.
5. The walls of the tank are adiabatic.

The unsteady-state macroscopic energy balance

$$\frac{d}{dt} E_{\text{tot}} = -\Delta \left[\left(\hat{U} + p\hat{V} + \frac{1}{2} \frac{\langle \vec{v}^2 \rangle}{\langle \vec{v} \rangle} + \hat{P} \right) m \right] + Q + W, \text{ where}$$

$E_{\text{tot}} = U_{\text{tot}} + K_{\text{tot}}$, reduces to

$$\frac{d}{dt} \Delta U_{\text{tot}} = -\Delta(\Delta \hat{U} m) + Q \quad (1)$$

(continued)

because the kinetic and potential energy in the accumulation term and the work term W as well as the kinetic and potential energy terms may be neglected.

$\Delta U_{tot} = WC_p(T - T_o) \cong wC_p(T - T_o)$. Furthermore, the rate of heat addition to the system Q is given by $Q = \tilde{U}A(T_s - T)$. Hence Eq. (1) becomes

$$wC_p \frac{d(T - T_o)}{dt} = \tilde{U}A(T_s - T) - mC_p(T - T_o) \quad (2)$$

Multiplying through by $1/mC_p(T_s - T_o)$, Eq. (2) becomes

$$\begin{aligned} \frac{wC_p}{mC_p(T_s - T_o)} \frac{d(T - T_o)}{dt} &= \frac{\tilde{U}A}{mC_p(T_s - T_o)} (T_s - T) - \left(\frac{T - T_o}{T_s - T_o} \right) \\ \frac{w}{m} \frac{d}{dt} \left(\frac{T - T_o}{T_s - T_o} \right) &= \frac{\tilde{U}A}{mC_p} \left(1 - \frac{T - T_o}{T_s - T_o} \right) - \left(\frac{T - T_o}{T_s - T_o} \right) \end{aligned} \quad (3)$$

Introducing the dimensionless variables

$$\Phi = \frac{T - T_o}{T_s - T_o}, \quad n = \frac{m}{w} t, \quad B = \frac{\tilde{U}A}{mC_p}$$

Eq. (3) becomes, $\frac{d\Phi}{dn} = B(1 - \Phi) - \Phi$, or

$$\frac{d\Phi}{dn} + \Phi(1 + B) = B \quad (4)$$

which is a first-order linear differential equation of the form

$$\frac{dy}{dx} + Py = Q$$

The solution to this equation is

$$ye^{\int P dx} = Qe^{\int P dx} + \text{constant}$$

Applying this principle to Eq. (4), we find that the integrating factor is $e^{(1+B)n}$. The constant of integration is found to be $-B/(1+B)$ from the boundary condition $n = 0, \Phi = 0$. The final expression for Φ , the reduced temperature is

(continued)

$$\Phi e^{(1+B)n} = \left(\frac{B}{1+B} \right) (e^{(1+B)n} - 1).$$

the expression for n as a function of B and Φ is,

$$n = \left(\frac{1}{1+B} \right) \ln \left[\frac{B}{B - \Phi(1+B)} \right] \quad (5)$$

b. Numerical calculation;

$$T = 180^\circ\text{F}; \quad T_o = 120^\circ\text{F}; \quad T_s = 220^\circ\text{F}; \quad A = 23.9 \text{ ft}^2; \quad w = 6000 \text{ lb};$$

$$\bar{U} = 100 \text{ Btu/(hr)(ft}^2\text{)(}^\circ\text{F)}; \quad m = 1200 \text{ lb/hr}; \quad C_p = 1.0 \text{ Btu/(lb)(}^\circ\text{F)}.$$

$$B = \frac{(100)(23.9)}{(1200)(1.0)} = 1.99; \quad \Phi = \frac{180 - 120}{220 - 120} = 0.60$$

From Eq. (5) we find that $n = 0.777$.

$$t = \frac{nw}{m} = \frac{(0.777)(6000)}{1200} = \boxed{3.89 \text{ hr}}$$

c. If heat-transfer area is doubled, $n = 0.28$. thus,

$$t = \boxed{1.40 \text{ hr}}$$

Then, the greater the area available for heat transfer, the greater the amount of heat transferred to the suspension, and consequently, the less the time required for the effluent temperature to reach a given value.

7.24 We shall use the same nomenclature used in problem 7.23. The following assumptions are made:

1. Steam temperature remains constant in coil.
2. Density and heat capacity of water do not change very much with change in temperature.
3. Because the fluid is approximately incompressible.
 $C_p = C_v$.
4. Agitator maintains uniform temperature throughout.

(continued)

5. Heat transfer coefficient is independent of position and time.
6. The walls of the tank are adiabatic.

We choose the fluid within the tank as our system. Kinetic and potential energy may be neglected in this position. Since the work term is zero and there is no outlet stream, $m_2 = 0$. Hence, for this system the energy balance reduces to

$$\frac{d}{dt} U_{tot} = mH_1 + Q \quad (1)$$

which states that the internal energy of the system is increasing because of the addition of fluid with enthalpy H_1 and because of the addition of heat Q through the steam coil.

In view of the fact that U_{tot} and H_1 cannot be given absolutely, we now select the inlet temperature T_o as the thermal datum plane. Then $\hat{H}_1 = 0$ and $U_{tot} = \rho C_p V(T - T_o) \equiv \rho C_p V(T - T_o)$. Furthermore, the rate of heat addition to the system Q is given by $Q = \bar{U}A(T_s - T)$. Hence Eq. 1 becomes

$$\rho C_p \frac{d}{dt} V(T - T_o) = \bar{U}A(T_s - T) \quad (2)$$

Now the instantaneous area and volume are simply related to the total available area and volume according to the relations

$$V(t) = \frac{mt}{\rho}; \quad A(t) = \frac{mt}{\rho V_o} A_o \quad (3,4)$$

where $\rho V_o / m = \tau_o$ is the time required to fill the tank. Substitution of these expressions in Eq. 2 gives

$$m \hat{C}_p t \frac{d(T - T_o)}{dt} + \hat{C}_p m (T - T_o) = \bar{U} A_o \frac{mt}{\rho V_o} (T_s - T) \quad (5)$$

which is to be solved with the initial condition that at $t = 0$, $T = T_o$.

The following reduced variables are introduced now:

$$\phi = \frac{T - T_o}{T_s - T_o} = \text{reduced temperature} \quad (6)$$

(continued)

$$n = \frac{t}{t_o} = \frac{mt}{\rho V_o} = \text{reduced time} \quad (7)$$

In order to rewrite Eq. 5 in terms of the foregoing dimensionless variables, the entire equation is multiplied through by $[1/mC_p(T_s - T_o)]$ to obtain

$$\left(\frac{\bar{U}A_o}{mC_p}\right)\left(\frac{mt}{\rho V_o}\right)\left(1 - \frac{T - T_o}{T_s - T_o}\right) = \left(\frac{T - T_o}{T_s - T_o}\right) + t \frac{d}{dt} \left(\frac{T - T_o}{T_s - T_o}\right) \quad (8)$$

or

$$Bn(1 - \phi) = \phi + n \frac{d\phi}{dn} \quad (9)$$

in which $B = \bar{U}A_o/mC_p$ is a dimensionless group appearing in the differential equation. The equation may be further simplified by noting that if the last term is multiplied by B/B then the reduced time variable always appears in the combination Bn , which combination is designated by α . Thus,

$$\frac{d\phi}{d\alpha} + \left(1 + \frac{1}{\alpha}\right)\phi = 1 \quad (10)$$

$$\phi = 0 \quad \text{at} \quad \alpha = 0 \quad (11)$$

is the final analytical statement of the problem. Eq. 10 is a first-order linear differential equation. Its solution is

$$\phi = 1 - \frac{1 - \exp(-\alpha)}{\alpha} \quad (12)$$

where the constant of integration has been determined from the initial condition (11). Finally, the temperature of the liquid in the tank, when it has been filled, is given by Eq. 12 when $n = 1$ (or $\alpha = B$); in terms of the original variables, this result is

$$\frac{T_f - T_o}{T_s - T_o} = 1 - \frac{1 - \exp(-\bar{U}A_o/mC_p)}{(\bar{U}A_o/mC_p)} \quad (13)$$

For the data given in the problem,

$$B = \frac{(100)(32.9)}{(1200)(1.0)} = 2.74. \text{ For this value, Eq. (13) gives } (T_f - T_o)/$$

(continued)

Solutions - Chapter - 7

$$(T_s - T_o) = 0.659, \text{ whence } T_f = \boxed{155.5^\circ\text{F}}$$

When the tank is half full, $n = 1/2$, $\alpha = \alpha/2$. Thus

$$\phi = 1 - \frac{1 - \exp\left(-\frac{\alpha}{2}\right)}{\frac{\alpha}{2}} = \frac{1 - 0.254}{1.37} = 0.455, \text{ whence}$$

$$T_f = \boxed{129.0^\circ\text{F}}$$

5 a. If heat losses from the top and the bottom of the tank are neglected, the resulting energy balance is

$$\rho V C_p \frac{dT}{dt} = \bar{U} A (T_s - T) \quad (1)$$

$$\int_{T_o}^{T_s} \frac{dT}{T_s - T} = \int_0^t \frac{\bar{U} A}{\rho V C_p} dt \quad (2)$$

or

$$= \ln[(T_s - T)/(T_s - T_o)] = \frac{\bar{U} A}{\rho V C_p} dt \quad (3)$$

Numerical Calculations:-

$$\frac{\bar{U} A}{\rho C_p V} = \frac{(40)(25\pi)}{(62.4)(1.0)(125\pi/4)} = 0.513 \text{ hr}^{-1}. \text{ Since}$$

$T_s = 230^\circ\text{F}$, $T = 170^\circ\text{F}$, and $T_o = 70^\circ\text{F}$, the time necessary to raise the temperature of the tank contents to 170°F is given by Eq. 3. Thus,

$$t = \boxed{1.91 \text{ hr}}$$

b. If the heat losses from the top and the bottom of the tank are taken into account, the energy balance for the system is,

$$\rho V C_p \frac{dT}{dt} = \bar{U} A (T_s - T) + \bar{U}_o A_o (T_{air} - T) \quad (4)$$

(continued)

where $\bar{U}_o$ = overall heat transfer coefficient for both the top and the bottom of the tank. If we let $a = UA + U_oA_o$ and $K = UAT_s + U_oA_oT_{air}$, Eq. 4 becomes

$$\frac{\rho V C_p}{a} \frac{dT}{dt} = \frac{K}{a} - T \quad (5)$$

and when integrated we obtain the following equation:

$$-\ln \left(\frac{K - aT}{K - aT_o} \right) = \frac{a}{\rho V C_p} t \quad (6)$$

For the data given in this problem,

$$a = (40)(25\pi) + (10)(25\pi/2) = 3540 \text{ Btu / (hr)}(^{\circ}\text{F})$$

$$K = (40)(25\pi)(230) + (10)(25\pi/2)(70) = 7.50 \times 10^5 \text{ Btu/hr.}$$

Thus,

$$t = \boxed{2.10 \text{ hr.}}$$

SOLUTIONS TO THOUGHT PROBLEMS

Section 1.1

1. a. Gravity is not a force, it is an acceleration. Weight is a force.
b. A person has mass in kg but weight in Newton's even though common usage may be otherwise.
2. A person exhales $2 \times 10^7 \text{ cm}^3$ daily of which 4% is CO_2 . Thus, $8 \times 10^5 \text{ cm}^3$, or say 1.57 kg of CO_2 is exhaled of which 430 g are C. Carbon in the biosphere contains ^{14}C which produces beta particles at the rate of 0.3 beta particles/second/gram of C, or you exhale 1.1×10^7 particles per day. Do you violate the law?
3. (1) Loss of mass with polishing.
(2) loss of weight because of a change in gravity.
(3) Errors in measurement.

Section 1.2

1. If the question refers to mass, the answer is yes. If the answer refers to any other measure, such as moles, the answer is no.

Section 1.3

1. Dealers say that higher summer gasoline consumption means more gasoline gets shrunk than expanded. The expansion of those cold shipments is minor compared to what a dealer loses to contraction the rest of the year.
2. Most organic bromides or iodides can be dissolved in a suitable organic solvent and yield a solution with the proper specific gravity to discriminate between the jades and arbite, serpentine, and other imitators of jade. For example, methylene iodide (sp. gr. = 5.7) is a liquid at room temperature and can be blended with ethanol to give a harmless liquid of the desired specific gravity.
3. Solution:

The density of gasoline is 0.81 and that of pentane 0.69. On more than one occasion tanks have overflowed because the contents were replaced by a liquid of lower specific gravity. The operators did not realize that the level indicator measured weight, not volume.

Section 1.4

1. Follow the regulations of the U.S. Department of Agriculture which has proposed a strict permit system that, through tamper-proof computerized controls, assures that elevator operators adhere to Agriculture Department standards. Alternatively, grain could be priced at its dry weight on an industry wide basis (which is not currently done).

Section 1.5

1. The temperature probably is just a conversion from 2700°F ; hence the answer is 2.
2. Examine Figure 1.4 for suggestions.
3. The thermocouple well was set only one inch into a 48 inch pipeline. When it rained, the exterior of the pipeline, and the thermocouple, would cool, causing a furnace to heat the residual going into the pipeline, excessively as it turned out.

Section 1.6

1. The essential point is that the covering paper can bulge out a bit so that the air pressure inside the glass is lowered. The pressure difference keeps the water in place. The water in the glass is compressed by the air. A glass plate on top of the completely filled glass is acted upon by the external air pressure and an equally large force from the compressed water on the other side. Thus, there is no pressure difference to support the weight of the water in the glass.
2. The tank, like most such tanks, was designed for a vacuum of 2 1/2 inches water gauge only (0.1 psi or 0.6 kPa), and would collapse at a vacuum of about 6 inches water gauge (0.2 psi or 1.5 kPa).

If the tank had been filled instead of emptied it might have burst because it was designed to withstand a pressure of only 8 inches water gauge (0.3 psi or 2 kPa) and would burst at about three times this pressure. Whether it burst or not would have depended on the depth of water above the end of the hose.

3. The answer surprisingly is yes! Such pressures exist all around us—the pressure of sap in trees often gets as low as -2 MPa. Pressures as low as -20 MPa have been obtained in water in the laboratory!

When discussing pressure in gases, we often define the pressure as "the sum of impulses transferred to the wall of a container per unit time and area". By this definition, pressures lower than a vacuum could not be produced. For pressures to be lower than a vacuum, our molecular interpretation would have to include attractive forces between the molecules of the fluid and the walls of the container. Such forces are typical of liquids but not of gases.

Attractive and repulsive forces between molecules correspond well to the macroscopic concepts of tension and compression. If we consider material with normal stresses lower than the pressure of a vacuum to be under tension and compression. If we consider material with normal stresses lower than the pressure of a vacuum to be under tension and material with normal stresses higher than the pressure of a vacuum to be under compression, then one way to distinguish liquids from gases is that liquids are fluids that can sustain compression or tension and gases are fluids that can sustain only compression. A lucid description of osmotic pressure is presented by Hammel and Scholander (H.T. Hammel and P.F. Scholander, *Osmosis and Tensile Solvent* (Springer Verlag, Berlin, 1967), pp. 1-73.)

4. During the fall, the force on the water exerted by gravity drops to zero.

Section 2.1

1. The oxygen concentration dropped from normal to approximately 1% in just under 24 hours because of rapid rusting of the evaporator's low-carbon-steel interior. The problem of low oxygen concentration was also compounded by the fact that the workers opened only one of the two manholes in the unit--when both were open, a natural draft was created that changed the air in the evaporator in less than a minute.
2. Many leak detection methods monitor the level of the material inside the tanks. Proponents of these methods say you can tell what the tank is doing by careful inventory control. Accurately detecting level changes that a leak would cause is not difficult, but there are other changes that can affect the volume in the tank that have nothing to do with the leak itself. The temperature of the fluid in the tank, tank deformation, air pockets within the tank, the angle at which the tank sits and a number of other factors can skew volumetric data.

Leakage can be detected by monitoring the environment in the immediate vicinity of the tank. But if you detect gasoline at a gas station, there's always the question that it could be the result of poor housekeeping on the surface, or a leak from the gas station across the street.
3. The black cylinder had contained oxygen. All persons who are responsible for handling cylinders, particularly persons in charge of breathing apparatus, should be familiar with the color codes for cylinders.
4. Yes because the solubility of oxygen in seawater is very low.

Section 3.1

1. By the conservation of mass in the closed system, the answer is d.
2. A pipe connected to system at the desired level (to retain some liquid) connected to an orifice operating in parallel with the controller will allow liquid to pass if the controller ceases to separate.

Section 3.2

1. The material balances are:

$$\begin{aligned}
 (1) \quad 0.10(10) + 0.30(6) &= 0.175(16) \quad \text{checks, and does not contain unknowns} \\
 (2) \quad 0.90(10) + 0.50(6) &= W_2^P(16) \quad \text{is uncoupled} \\
 (3) \quad 0.0(10) + 0.20(6) &= W_3^P(16) \quad \text{is uncoupled} \\
 (4) \quad 1 &= 0.175 + \omega_2^P + \omega_3^P
 \end{aligned}$$

Only two unknowns exist if you introduce equation (4) into (1) - (3). The rank of the coefficient matrix of (2), (3), and (4) is 2, hence the problem has a unique solution.

An alternate solution is solve eq. (2) for ω_2^P and solve eq. (3) for ω_3^P , and then check values using eq. (4).

Section 3.3

1. You can detect counterfeit gold or silver by weighing and measuring a coin or bar against the issuing mint's specifications. Modern counterfeiters may have mastered the appearance of their fakes but the principle of density--the ratio of mass to volume--has not changed. Gold has a greater density than the common metals such as lead, brass, copper and steel. This means that it is impossible to make a common metal fake identical to a genuine coin in both weight and size from these metals.

References	gold	Silver	copper	lead	iron	nickel	zinc
Perry	19.30	10.49	8.93	11.33	7.86	8.90	7.135
CRC	18.88	10.50	8.96	11.35	7.87	8.90	7.133
S & E of materials (Askeland)	19.30	10.49	8.93	11.36	7.87	8.90	7.133
Himmelblau	--	--	8.92	11.34	7.70	8.90	7.140

Silver can be imitated, but if made of a lead/tin alloy it would be too soft. Use 79.1% Pb, 20.9% Sn.

2. If the ash in the sludge is identical to the ash in the residual ash, then on the basis of 100 kg of sludge:

$$\frac{67 \text{ lb ash}}{100 \text{ kg sludge}} \times \frac{100 \text{ kg residual ash}}{87 \text{ lb ash}} \times \frac{184 \text{ mg of Cd}}{1 \text{ kg residual ash}} = 142 \text{ mg}$$

This number can be compared with 169 kg in the sludge so that $169 - 142 = 27 \text{ mg}$, (16%) is lost up the stack if the assumptions made hold.

Similarly for Pb, compare 307 mg with 412 mg in the sludge, and for Zn compare 1496 mg with 1554 mg. Not all of the heavy metals end up in the residual ash.

Section 3.4

1. A service engineer from the manufacturer was called to test the combustion controls and found that the flue gas contained no excess oxygen and approximately 4% combustible gas. The ratio of combustion air to fuel was increased until the flue gas contained zero percent combustible gas and then the steam flow increased to the full 120,000 lb per hour capacity. In determining the cause of the combustion control malfunction, it was found that moisture from the products of combustion had condensed in the piping to the combustion air flow controller causing erroneous action. To eliminate this problem, an oxygen and combustible recorder was installed and a regular maintenance contract was set up with the combustion control manufacturer. The installed cost of the new control equipment was \$95,000 vs a loss of \$54,900 in fuel in the two months.

2. Calculation shows the statement to be wrong. If the average car gets 25 miles per gallon, 26,000 miles corresponds to an output of about 11 tons of carbon dioxide. It has been estimated that a young apple tree produces about 44 lb of sugar per growing season, which is equivalent to an uptake of about 66 lb of carbon dioxide. Thus even 100 young apple trees would not remove the carbon dioxide produced annually by an average car until the trees had grown to more than twice their size when planted.

3. Fossil fuels contain more carbon than hydrogen. This is especially so for coal (over 95% of our fossil-fuel supply).

We prefer gaseous and liquid rather than solid fuels. So, there has been much effort to develop processes that convert coal, or waste materials, to gaseous and liquid forms as supplements to natural gas and petroleum. In all these processes, the main technical consideration has been to lower the carbon-to-hydrogen ratio, by adding hydrogen.

Superficially, it might seem that this increase in the relative amount of hydrogen in the fuel would lessen CO_2 emissions. But that is not the case, because the production of the hydrogen itself inevitably consumes more energy (derived from carbon-containing fuel) than is subsequently regained when the hydrogen in the synthesized fuel is burned. In short, there is a net addition of carbon dioxide to the atmosphere.

Gases from coal, cellulose, and other waste materials via most of the known processes contribute 10 to 200 percent more carbon dioxide than would pure carbon for the same heat availability. The story is analogous with respect to ethanol as an alternative automotive fuel: In the absence of free ethanol, any process to manufacture that alcohol would give off at least twice as much CO_2 as would the use of gasoline, instead of ethanol, in the vehicle. It is true that using ethanol in automobiles gives off less carbon monoxide, but this is perhaps overshadowed by the danger posed by CO_2 .

Another point should be made. Analysis shows that all of the synthetic fuels are intrinsically less efficient (based on actual heating value vs. that theoretically obtainable from the fuel's constituents in elemental form) than the fuel forms as they occur in nature.

Section 3.6

1. To protect the pump, a minimum-flow line (line with an orifice) normally is created leading from the pump's main discharge line back to the suction tank.

Section 4.1

1. The loss of free oxygen is more or less compensated for by reaction products such as CO and CO_2 (and also H_2O which, however, condenses). The important observation is that the water level inside the glass does not rise gradually. As the gas inside the glass is heated by the candle, the gas pressure increases and gas leaks out. (Some hot air is also caught in the glass as it is lowered towards the candle.) When the candle goes out, the gas cools off rapidly, its pressure decreases, so that water is forced into the glass.

2. In fact, this statement is wrong, and is wrong regardless of how one interprets the word "empty". If empty means evacuated or containing helium at one atmosphere pressure, then it is obviously untrue. On the other hand, if empty means containing *air* at one atmosphere then it is still untrue, although only slightly. The can has a volume of about 43 cubic inches and when full is said to contain 0.21 cubic feet of helium, the air inside would still weigh a bit less than the compressed helium.

Two possibilities for this error suggest themselves. One, the author of the statement neglected to carry out the computation, and just guessed (wrongly) that the compressed helium would have a mass less than the same can full of air at atmospheric pressure. Another explanation possible is that the author misunderstood the nature of buoyancy, and fell into the trap of thinking that since "helium rises," it will exert an upward (buoyant) force from inside the can and cause it to feel lighter than if the can contained air or even a vacuum.

3. Either p , V , n , or T would have to be rescaled, and the rescaled variables would not be compatible with the underlying definitions of the variables as used in other calculations. For example, T could be rescaled as $T^* = 8.314T$ if the usual $R = 8.314 \text{ J/(g mol) (K)}$ was revised to a value of R equal 1 J/(g mol) (K) .
4. No. The change in buoyancy caused by the decrease in volume has to be taken into account. The small volume displaces less air, and this volume is equivalent to the volume of escaped air. No weight loss should be observed.

Section 4.2-2

1. At the bottom of the well the pressure is 1400 psi (9600 kPa) and the temperature reaches 530°F (277°C). Oxidation takes place without boiling which would make it very difficult to clarify the effluent after oxidation. Also, the oxygen concentration in the water is much higher at 1400 psia.
2. At that depth, a gas would be under a pressure of 787 psi. A bubble of 3.5 bbl will expand to 222 bbl on reaching the surface. The uncontrolled gas expansion in the marine riser can be dangerous. When the annular is opened and releases the trapped gas, the bubble will slip through the mud in the riser.

The pressure in the bubble will be determined by the amount of mud above the bubble. The volume of the bubble can be estimated by $pV = znRT$. Thus, as the bubble migrates half the distance remaining to the surface, its volume will more than double.

The following list gives the size of a 3.5-bbl bubble as it migrates to the surface from a depth of 1,000 ft.

Top	Bubble depth, ft.		Bubble volume
	Bottom		
1,000	1,011		3.5
500	521		7
250	293		14
125	210		28

Above 125 ft. the bubble no longer slips through the mud, but pushes the remaining mud out of the riser. The bubble volume will expand eight times its size from this point. This expansion is very rapid and can put excess pressure on the diverter system.

Section 4.3

1. Water entered the line containing the Dowtherm from the previous shutdown. The two liquids are immiscible, and each exerted its own vapor pressure so that the total pressure was the sum of the Dowtherm (30 psia) and water (110 psia) or 125 psia.
2. At 144°C the liquid butadiene would have expanded to fill the tank, but tests showed that the tank would expand enough so that it would not rupture at 160°C. Further tests showed that a dimerization of butadiene to vinyl cyclohexene (an exothermic reaction initiated at 100°C) would produce a rapid rise in temperature to over 500°C, hence the pressure exceeded the bursting pressure of the tank.
3. Boiling the water will not help unless the temperature is at least 212°F (100°C). Consequently, the water must be heated in a pressure vessel if you are in the mountains.

Section 4.4

1. The gasoline dissolved in the water in the tank to its equilibrium concentration, but the equilibrium concentration when in contact with air is quite different--much lower--than in water, hence when in the sewer, gasoline left the water as a vapor and a spark started a fire.
2. The probe can work well in a dilution range from 2 to 1 to 20 to 1. The effect of fluctuations of the stack pressure can be less than 6%. A glass wool plug should be used to filter out particulates. Because of error involved in the dilution, the error in gas analysis is magnified.
3. In combustion calculations we estimate the quantity of dry air required to burn a given amount of fuel. In reality, the atmospheric air is never dry; it consists of some moisture, depending on the relative humidity and dry bulb temperature. To compute the partial pressure of water vapor in the flue gas, which is required for calculating nonluminous heat transfer, we need to know the total quantity of water vapor in flue gases, a part of which comes from the combustion air.
Also, when atmospheric air is compressed, the saturation vapor pressure of water increases, and if the air is cooled below the corresponding water dew point, water can condense. The amount of moisture in the air or gas fixes the water dew point, so it is important to know the amount of water vapor in the air or flue gas.

Section 4.5

1. The tanks were not blanketed with nitrogen and there was an explosive mixture of naphtha vapor and air above the liquid in the tanks. The source of ignition was static electricity. The pumping rate was rather high so that the naphtha flowing through the pump and lines acquired a charge. A spark passed between the liquid in the tank and the roof or walls of the tank, igniting the vapor-air mixture.

There are several ways to preventing similar explosions:

1. Use nitrogen blanketing or floating roof tanks
2. Use anti-static additives; they increase the conductivity of the liquid so that charges can drain away rapidly to earth (provided equipment is grounded). However, make sure that the additives do not deposit on catalysts or interfere with chemical operations in other ways.
3. Minimize the formation of static electricity by keeping pumping rates low (less than 3 m/s for pure liquids but less than 1 m/s if water is present) and avoiding splash filling. Filters and other restrictions should be followed by a long length of straight line to allow charges to decay.
2. This dry ice jet contains solid and gaseous components. Two categories of cleaning exist, one for removing solid particles and one for hydrocarbons. In the former, particles are dislodged and removed by a combination of the gas aerodynamic drag force and collisions between the solid CO₂ snow and the surface particles. Collisions between the snow and surface particles are believed to be responsible for the snow removing particles of all sizes, micron and submicron.

In the case of hydrocarbons adhered to the surface, liquid carbon dioxide forms by the pressure increase when the snow impacts the surface. Fortunately, the triplet point of CO₂ is only at four atmospheres pressure, and hydrocarbons are known to be soluble in the liquid.

3. Reducing the pressure on gaseous carbon dioxide causes a transition to a combination of solid and liquid or gas. Examine the CO₂ chart.
4. Yes, by going through a process that first gets beyond the critical point and then cooling the fluid and changing the pressure.
5. (a) The vapor pressure of a gasoline is 14.7 psia at 130°F.
(b) The vapor pressure of a particular mixture of water and furfural is 760 mm at 99.9% °C.
6. If the vapor of the fluid being loaded dries all of the air out of the tank, the only vapor left is the vapor of the liquid, and its vapor pressure may be less than the atmospheric pressure outside the tank. Coast Guard regulations require that pressure sensors be installed near the hose connection at the dock, and systems (vacuum breakers) be installed to inject inerting or diluting, or enriched, gas into the vapor space.

Section 4.6

1. Possible causes are:

1. Diffusion and convection of air (oxygen) could take place through the open manhole during lunch.
2. Some of the CS₂ vapor might condense allowing air to pass into the tank.
3. N₂ and CS₂ might cool and allow air to flow in.

2. The National Transportation Safety Board determined that the probable cause of the initial and subsequent explosions was the ignition of benzene vapors which were present both within the open cargo tanks and on the main deck of the tankship. The investigative record in this case does not contain sufficient information to determine the ignition source of the initial explosion. The probable source of ignition of the subsequent explosions was the heat produced from the preceding explosions.

As benzene cargo was discharged from the V. A. FOGG at the Phillips Petroleum Company and Dow Chemical Company terminals, air replaced the liquid benzene. The evaporation of the benzene residue which remained on the walls and bottom of the cargo tanks ensured a mixture of benzene vapor and air in the tanks. The lower and upper explosive limits of benzene vapor in air are 1.4 and 8.0 percent by volume, respectively.

Using the estimated air and water temperatures which affected the V. A. FOGG on February 1, it was determined that the benzene vapor concentration in the cargo tanks probably ranged between 5.7 and 8.0 percent.

$$3. \text{ Density} = \frac{\text{mass}}{\text{volume}} = \frac{(n) (MW)}{V}$$

$$\text{Density of air} = \frac{n_1 (y_{H_2O} MW_{H_2O} + (1 - y_{H_2O}) MW_{air})}{V}$$

$$= \frac{n_1}{V} (y_{H_2O} (18) + (1 - y_{H_2O}) (29))$$

On day 1, $y_{H_2O} > y_{H_2O}$ on day 2

On a humid day the air is less dense. The "heavy" or "muggy" feeling of the air occurs because of reduction of evaporation from the surface of the skin.

Section 4.7

1. The cold liquid condensed the steam in the tank, and the pressure in the tank was lowered so rapidly that the air flow through the vent was not enough to prevent a partial vacuum from forming in the tank sufficient to collapse it.

Section 5.1

1. The data gives 151,000 gal/(mi)³. Assume land used for crops is 738×10^3 mi². 10.7% would be used for ethanol production.
2. About 3×10^9 bbl oil/yr are used; 10% is 3×10^8 bbl. $3 \times 10^8 / 3.26 = 9 \times 10^{11}$ tons coal. If 6.5×10^8 tons of coal are mined each year, the fraction is 14%.
3. All balls have the same initial kinetic energy, and all have the same final kinetic energy, hence speed.
4. All the statement except for the part that says "the metal oven tray ...contains much more heat".

Section 5.2

1. You can write

$$\text{and show} \quad dH - dU = d(pV) = p dV + V dp$$

$$C_p - C_v = \left(\frac{\partial H}{\partial T} \right)_p - \left(\frac{\partial U}{\partial T} \right)_v = \left(\frac{\partial U}{\partial V} \right)_T \left(\frac{\partial V}{\partial T} \right)_p + p \left(\frac{\partial V}{\partial T} \right)_p$$

The term on the right hand side is not zero. $(\partial V/\partial T)_p$ can be evaluated from the coefficient of thermal expansion $(1/V) (\partial V/\partial T)_p$; $(\partial U/\partial V)_T$, the internal pressure, is hard to find but can be calculated from the coefficient of thermal expansion; $(\partial V/\partial T)_p$ is the compressibility. Examples of such calculations give the following errors for $[(C_p - C_v)/C_v] \times 100$: Hg, 12.7%; CH_3OH , 22%; C_6H_6 , 30%; Ag, 4%.

2. Fire walkers traverse only about 10 feet of coals, thinly spread, and do so rapidly. They dip their feet in ice water before setting out, or stand on damp grass. The Leidenfrost effect occurs, the same effect which explains why water droplets on a hot griddle take so long to vaporize. They float on insulating layers of vapor that form very quickly at the bottoms of the droplets.

Fire walkers' footprints are momentarily dark, which indicates that the coals cool quickly. The cooling results in part from compression of ash and depletion of oxygen at the glow front and the flow of heat from coals to feet. Fortunately for fire walkers, the specific heat of feet, with their high water content, is much greater than the specific heat of coals. Coal and coal ash are also insulators. Once the feet cool the surface of glowing coal, heat travels relatively slowly from the hot interior of the coal to the cooler surface.

3. Steps to take:

- (1) insulate tank (but see (7) below) but it may aid corrosion, hinder inspection
- (2) cover tanks with earth (same problems as (1))
- (3) emergency depressurize systems and pipe (expensive)
- (4) liquid withdrawal/transfer system (only if very rapid--makes tank more vulnerable)
- (5) keep tank full so $\int C_p dT$ absorbs heat transfer
- (6) admit water into tank to replace vapor/liquid losses (can over pressurize, extensive venting)
- (7) apply water spray (must be where needed)

4. No. A system at equilibrium at constant temperature and pressure can have some of the material change phase.

Section 5.3

1.
 - a. No
 - b. No. Oversulding consumes more energy.
 - c. No. Warm room air is pulled up the chimney.
 - d. Yes. The room will need to be cooled down when you return, but you'll still save energy.
 - e. Yes, but be sure the gas is off, too, and that the pilot light is relit before you turn the furnace back on.
 - f. No. An average shower saves about 5 gallons of hot water compared with a bath, or (if daily) almost 2,000 gallons of hot water a year.
 - g. No. Long-life bulbs are not energy-savers.
 - h. Yes. A 40-watt fluorescent gives off 80 lumens per watt, while a 60-watt incandescent yields only 14.7 lumens per watt.
 - i. No. The range will heat the refrigerator.
 - j. Yes. Driving 55 saves about 20 percent.
 - k. No. These accessories all consume energy.
2. Liquid is sometimes transferred from one tank to another by gravity. Overfilling has occurred when liquid flows from a tall tank to a short one. Overflow can occur when liquid is transferred from one tank to another of the same height several hundred yards away because a slight slope in the ground is sufficient to cause the lower tank to overflow.
3. Aside from possible *practical* difficulties (such as the height of the tower): questions are:
 1. Will the system run as described?
 2. If so, does it constitute perpetual motion; or, if not, from what source does the energy come?
 3. If it would not run, point out any fallacy in the reasoning above.

The answer to the perpetual motion problem is that the work needed to expand the hydrogen and oxygen is at least equal to the energy developed by the turbine; the fact that the water is electrolyzed does not significantly change the problem from one in which two pistons are moved away from one another inside a cylinder, creating a vacuum between them. In both cases a pressure is exerted through a volume. The machine will not run. Assuming that the water is of negligible volume, that W pounds of water are being used, that the air is of constant density ρ , and that the air stops at the top of the column whose height is H , then the energy developed by the turbine is given by WH , and the weight of air which must be displaced must equal the weight of the water W . If the volume of air is V .

$$V = W, \text{ or } V = W/p$$

The work done in expanding the air is the volume through which the air is expanded times the pressure: $\text{Work} = W/p \times H_p = WH$.

This is the same as the work developed by the turbine. Actually, of course, the assumptions about the characteristics of the air are not strictly correct, but the same result could be obtained (with considerable more work) by finding $\int_{h_{in}}^{h_{out}} p dv$.

4. Turn off the fuel burners and let the furnace cool to 1600°F (energy used = 0 MBtu). Reheat from 1600°F to 2200°F in 2.6 hours (energy used = 70 MBtu). Hold at 2200°F for 0.5 hours (energy used = 5.1 MBtu). Total energy used = 75.1 MBtu vs (10.2) 8 = 81.6 MBtu by holding at 2200°F.

Section 5.4

1. If efficiency is defined as $q/\Delta H^\circ_{rxn}$, each of the quantities q and ΔH°_{rxn} should be based on comparable amounts of fuel (or perhaps costs of fuel would be best?), such as unit mass or mole, be at the same standard state, and refer to the same ambient conditions. Whether the amount of excess air can be the same is uncertain, but if it is not or even if it is, the gaseous product composition will differ in each case, e.g., CH_4 vs. $CH_{1.8}$ fuels. The overall heat capacities will only slightly differ, but the water vapor content may differ per mole of CO_2 produced. To avoid condensing the water vapor, the natural gas products cannot be cooled as much as fuel oil combustion products.
2. Methanol added to gasoline has been reported to have some attributes that cause problems in automobiles (corrosion, vaporization, etc.). On the other hand, miles per gallon of a fuel is the important consideration and it is not proportional to calorific value. The Bank of America recorded millions of miles driven by its fleet of hundreds of cars, and showed that methanol blends increase mileage, as would be expected from the much greater efficiency of methanol in an engine that, however, was designed to use gasoline. Performance in terms of miles per million Btu in the blends is better than gasoline.
3. Efficiency drops more for values of the theoretical air-fuel less than 1 vs. greater than 1, and CO is produced in the former mode. Air pressure has little effect. Preheating the air, if possible at a cheap cost, helps some. Preheating the feed water also helps a bit. A high flue gas temperature results in a much more substantial loss in efficiency. A fuel that has a higher H to C ratio reduces efficiency for high H to C ratios. Fouled heat transfer surfaces reduce efficiency a bit.
4. The heat transfer is different because for a closed system $Q = \Delta U = \Delta H - p(\Delta V)$, and for an open system $Q = \Delta H$.
5. The improper design, operation, or use of thermal combustion systems may pose a threat to public health through emissions of potentially hazardous components of the wastes or their combustion byproducts. Incinerators can remove 99.99% of the hazardous waste occurring at concentrations > 1000 ppm in the feed, but incomplete combustion products indicate decomposition is not complete, and some of the intermediate products of combustion are also hazardous. The handling of the feed requires care as inadequate atomization and overfeeding leads to CO, unburned hydrocarbon, and difficult to detect hazardous species.

A good reference is *Science*, vol. 206, p. 781-795 (1979); there are innumerable others. Coal is about at the break even point. Whatever assumptions are made about the use of crop residues, substitution of coal for oil in the processing, etc. affect the conclusions.

6. Oxygen, because the N_2 in the product of combustion with air uses up some of the available energy pool.
7. Combustion of H_2 in air gives a theoretical flame temperature of $4060^\circ F$ but the actual temperature allowing for equilibrium is more like $3800^\circ F$. Preheating the fuel and air which might occur would raise both of these values.

Section 5.5

1. 20 hp is much less than 68 kW, insufficient even at 100% efficiency.
2. Comparisons are heavily dependent on the assumptions one makes relating to the performance and capacity of the electric versus the internal combustion engine (ICE) vehicle. Since no current electrically powered vehicle matches the cruising speed, acceleration, and range characteristics of competitive gasoline-powered cars, this type of comparison is always clouded by whatever is assumed as the minimum acceptable performance for the electric. If the electric car must have the power/energy capability to drive repetitively 54 miles between battery charges, a considerably heavier electric vehicle than 2800 lb is needed (more like 4000 lb is needed). A 50-mph road load power requirement is not a valid basis on which to size a power plant to propel highway vehicles.

Efficiencies are different from the table. Reasonable values are 36% thermal efficiency for the power generation facility, 91% electrical transmission efficiency, 10% refinery energy penalty charged to gasoline manufacturing, and 46% battery efficiency (assuming overnight recharge). The latter figure is considerably lower than the 70% figure in the table.

On this basis, the energy consumption for a currently feasible electric car used under city-suburban commuting conditions comes out to about 8300 Btu/mile versus 6000 Btu/mile for the Pinto-class gasoline powered car.

3. The ball levitates because as the air reaches the expansion section of the funnel, it slows down to fill the larger cross section, and since the air is faster above the ball than below it, the pressure is higher below the ball than above it.

Section 5.6

1. The heat of mixing of the compounds was exothermic and caused excess vapor to form and over-pressurize the storage tank.
2. Evolution of heat of mixing vaporized water, and drove some of the solution out of the tank.

Section 5.7

1. Advertisers and even some heating engineers appear to overlook latent heat of vaporization. The evaporation of 10 gallons of water a day (modest for the humidification of most houses) requires more than 80,000 Btu equivalent to the consumption of about 80 cubic feet of natural gas per day. This is approximately 10 percent of the natural gas needed to heat a modest home on an average winter day. It makes no difference if humidification is

accomplished merely by placing pans of water on radiators. Unless condensation of water vapor releases energy to the house, it doesn't appear as if you could save energy overall by turning down the thermostat 4°F.

2. Evaporative cooling is an excellent technology for low-cost cooling and works best in desert areas. In a swamp, the humidity is so high that little water evaporates, and, in addition, the humidity of the exit air is so high that conditions are uncomfortable for people.

Section 6.1

1. No. The solution method will have to be different than for continuous variables.
2. Variables associated with any other properties such as charge (changes have to be balanced), electrical and magnetic properties, etc.

Section 7.1

1. The equations for the time to drain each tank are:

Vertical cylinder

$$t = \frac{\pi D^2 \sqrt{h}}{\sqrt{8} C_d A_n \sqrt{g}}$$

Horizontal cylinder

$$t = \frac{\sqrt{8} L (D^{\frac{3}{2}} - (D-h)^{\frac{3}{2}})}{3 C_d A_n \sqrt{g}}$$

Cone

$$t = \frac{\sqrt{2} \pi \tan^2 \theta h^{\frac{5}{2}}}{5 C_d A_n \sqrt{g}}$$

Sphere

$$t = \frac{\sqrt{2} \pi h^{\frac{3}{2}} (D - \frac{1}{3}h)}{3 C_d A_n \sqrt{g}}$$

where:

A_n = orifice area, ft²

g = 32.2 ft/s²

t = time to empty, s

C_d = 0.61 for sharp-edged orifice

= 0.80 for short, flush-mounted tube

= 0.98 for rounded orifice

Assume the orifice coefficient is constant. Pick an orifice area, D , θ , h , L , and C_d that tanks are compatible (let h and D be the same). Then calculate t .

2. Refer to Problem No. 11 (p. 21) of the cited publication for the detailed information for instructors and the solution.

Solutions - Chapter - 1

1.42 $\rho_{\text{ice}} = 0.917 \text{ g/cm}^3$ Density of ice

$\rho_{\text{H}_2\text{O}} = 1.00 \text{ g/cm}^3$ Density of $\text{H}_2\text{O(l)}$

$\rho_{\text{alcohol}} = 0.791 \text{ g/cm}^3$ Density of pure alcohol

If the rum is 97 proof (48.5% EtOH), the density is 0.917 g/cm^3 . As the proof rises, the density of the solutions decreases below that of ice, causing the ice to sink.

1.43 Basis: 1 gal of solution.

Mass of solution:

$$\frac{1.0824 \text{ lb soln}}{\text{ft}^3 \text{H}_2\text{O}} \left| \frac{62.4 \text{ lb H}_2\text{O}}{\text{ft}^3 \text{H}_2\text{O}} \right| \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \left| \frac{1 \text{ gal}}{1} \right| = \boxed{9.03 \text{ lb soln}}$$

$$\text{Mass fraction KOH} = \frac{0.813 \text{ lb}}{9.03 \text{ lb}} = \boxed{0.09}$$

$$\text{Mass fraction H}_2\text{O} = 1 - 0.09 = \boxed{\frac{0.91}{1.00 \text{ Total}}}$$

1.44 $\rho_{\text{water at } 60^\circ\text{F}} = 0.99905 \text{ g/mL}$

$$\text{Sp. gr. of benzene at } \frac{60^\circ\text{F}}{60^\circ\text{F}} = \frac{0.879 \text{ g/cm}^3}{0.99905 \text{ g/cm}^3} = \boxed{0.879}$$

1.45

a. $\frac{0.90 \frac{\text{kg liq.}}{\text{m}^3}}{\frac{\text{kg H}_2\text{O}}{\text{m}^3}} \left| \frac{10^3 \text{ kg H}_2\text{O}}{\text{m}^3} \right| = \boxed{900 \frac{\text{kg liq.}}{\text{m}^3}}$

b. $\frac{1 \text{ m}^3}{900 \text{ kg liq.}} \left| \left(\frac{3.2808 \text{ ft}^3}{1 \text{ m}} \right)^3 \right| \frac{0.454 \text{ kg}}{1 \text{ lb}_m} = \boxed{0.0178 \frac{\text{ft}^3}{\text{lb}_m}}$

(continued)

Therefore, the temperature range where the mixture can exist in vapor and liquid is between 62.2°C and 81.7°C

4.101

The following vapor pressure data is taken from the 65th edition of the Handbook of Chemistry and Physics:

Component	760	1520	3800	7600	15200	30400	Temp. (in °C)
methane	-161.5	-152.3	-138.3	-124.8	-108.5	-80.3	
ethane	-88.6	-75.0	-52.8	-32.0	-6.4	23.6	
propane	-42.1	-25.6	1.4	26.9	58.1	94.8	
i-butane	-11.7	7.5	39.0	66.8	99.5	-	
n-butane	0.5	18.8	50.0	79.5	116.0	-	
n-pentane	36.1	58.0	92.4	124.7	164.3	-	

Using the computer program "ANTOINE" on the computer disk and the above data; the Antoine equation coefficients can be found for the form

$$p_i^* = \exp \left(A - \frac{B}{C + T} \right) \quad \text{where } T \text{ is in } ^\circ\text{C}$$

Component	y_i	A	B	C
methane	0.01	6.0247	241.64	237.82
ethane	0.15	7.0038	731.35	266.16
propane	0.25	6.9813	879.80	256.91
i-butane	0.14	7.4962	1311.12	295.98
n-butane	0.25	6.6283	818.76	218.61
n-pentane	0.20	6.8916	1069.77	230.54

- (a) The minimum temperature at which the mixture can exist totally as a vapor is just above the dew point. The dew point is calculated as follows:

$$\frac{1}{P_1} = \sum_{i=1}^6 \frac{y_i}{p_i^*} \quad p_1 = 100 \text{ psia} = 5170 \text{ mm Hg}$$

$$\frac{1}{5170} = \frac{0.01}{\log^{-1} \left(6.0247 - \frac{241.64}{237.82 + T_D} \right)} + \frac{0.15}{\log^{-1} \left(7.0038 - \frac{731.35}{266.16 + T_D} \right)}$$

(continued)

Solutions - Chapter - 4

Component	y_i	z_i
methane	0.0291	0.0015
ethane	0.3408	0.0656
propane	0.3251	0.2168
iso - butane	0.1068	0.1547
n - butane	0.1501	0.2942
n - pentane	0.0481	0.2672

(d) $(0.0291)(30.679) = 0.89276$ moles CH_4 in vapor of 1 total mole

$$= 89.28 \% \text{ CH}_4 \text{ in vapor}$$

$(0.0481)(30.679) = 1.4757$ moles C_5H_{12} in vapor of 20 total moles

$$= 7.38 \% \text{ C}_5\text{H}_{12} \text{ in vapor}$$

(e) 40 mole % condensed

$$L/F = 0.40$$

$$1 = \sum_{i=1}^6 \frac{x_{F_i}}{1 - \frac{L}{F} \left(1 - \frac{1}{K_i} \right)}$$

$$1 = \frac{0.10}{1 - 0.40 \left(1 - \frac{1}{K_{\text{CH}_4}} \right)} + \frac{0.15}{1 - 0.40 \left(1 - \frac{1}{K_{\text{C}_2\text{H}_6}} \right)} + \frac{0.25}{1 - 0.40 \left(1 - \frac{1}{K_{\text{C}_3\text{H}_8}} \right)}$$

$$+ \frac{0.14}{1 - 0.40 \left(1 - \frac{1}{K_{i-\text{C}_4}} \right)} + \frac{0.25}{1 - 0.40 \left(1 - \frac{1}{K_{n-\text{C}_4}} \right)} + \frac{0.20}{1 - 0.40 \left(1 - \frac{1}{K_{n-\text{C}_5}} \right)}$$

K_i is a function of temperature so this equation must be solved by trial and error, choosing a temperature and finding the values for K_i at that temperature.

The temperature must be somewhere between the dew point, 63.901°C , and 32.2°C where 69.588% was found to have condensed.

Trial	Temp. ($^\circ\text{C}$)	K_{CH_4}	$K_{\text{C}_2\text{H}_6}$	$K_{\text{C}_3\text{H}_8}$	$K_{i-\text{C}_4}$	$K_{n-\text{C}_4}$	$K_{n-\text{C}_5}$	Solution
1	45	20.0	6.00	1.80	0.92	0.61	0.220	0.9623
2	50	20.5	6.30	2.15	1.05	0.76	0.295	1.0272
3	48	20.3	6.25	2.10	0.98	0.72	0.275	1.0186
4	47	20.2	6.20	2.05	0.96	0.70	0.270	1.0035

(continued)

At 47°C, 40 mole % of the vapor has condensed.

(f) The point at which 100% of the vapor has condensed is the bubble point. This is calculated by

$$p_t = \sum_{i=1}^6 \log^{-1} \left(A - \frac{B}{C + T} \right) (x_i)$$

$$5170 = \log^{-1} \left(6.0247 - \frac{241.64}{237.82 + T_B} \right) (0.01) + \log^{-1} \left(7.0038 - \frac{731.35}{266.16 + T_B} \right) (0.15)$$

$$+ \log^{-1} \left(6.9813 - \frac{879.80}{256.91 + T_B} \right) (0.25) + \log^{-1} \left(7.4962 - \frac{1311.12}{295.98 + T_B} \right) (0.14)$$

$$+ \log^{-1} \left(6.6283 - \frac{818.76}{218.61 + T_B} \right) (0.25) + \log^{-1} \left(6.8916 - \frac{1069.77}{230.54 + T_B} \right) (0.20)$$

$$T_B = 1.31^\circ\text{C}$$

At 1.31°C, 100% of the vapor will have condensed

100,000 ft³ of gas

can be assumed that the gas is ideal because of its hydrocarbon character.

$$n = \frac{pV}{RT} = \frac{(100 \text{ psia}) (100,000 \text{ ft}^3)}{(10.73 \text{ psia}) (\text{ft}^3) (\text{lb mole}) (^\circ\text{R}) (550^\circ\text{R})}$$

$$n = 1694 \text{ lb moles of gas}$$

$$69.321 \% \text{ condenses at } 90^\circ\text{F}$$

$$(1694) (0.69321) = 1174.29$$

Using the liquid composition from part c, the moles of each individual component can be found.

Component	x_i in liquid	lb mol	mol. wt.	lb
methane	0.0015	1.761	16.04	28.25
ethane	0.0656	77.034	30.07	2316
propane	0.2168	254.588	44.09	11220
iso-butane	0.1547	181.664	58.12	10560
n-butane	0.2942	345.478	58.12	20080
n-pentane	0.2672	313.772	72.15	22640

(continued)

The following densities are taken from Perry's Handbook.

Component	lb	density (ft ³ /lb)	volume (ft ³)
methane	28.25	0.09877	2.790
ethane	2316	0.07550	174.9
propane	11220	0.03329	373.5
iso-butane	10560	0.02940	310.5
n-butane	20080	0.02822	566.7
n-pentane	22640	0.02544	576.0

Total volume = 2004.4 ft³

(2004.4 ft³) (7.481 gal/ft³) = 15,000

The pump will have to handle 15,000 gallons/minute.

4.102

$$F = C - P + 2 = 2 - 2 + 2 = 2$$

4.103 Ice point is lower than triple-point by 0.0095 C° due to fact that:

(1) the pressure is 1 atm rather than V.P. of H₂O

(2) air is dissolved in the H₂O

4.104 $F = C - P + 2$

(1) $F = 1 - 2 + 2 = 1$

(2) $F = 2 - 3 + 2 = 1$

(3) C

H 3 Elements so C = 3

O

$$F = 3 - 1 + 2 = 4$$

4.105 (1) $F = C - P + 2$

(continued)

$$(b) \% \text{ rel. humidity} = 100 \frac{P_{H_2O}}{P^*_{H_2O}} = 100 \left(\frac{0.874}{5.878} \right) = \boxed{14.9\%}$$

$$\% \text{ humidity} = \frac{\frac{P_{H_2O}}{P_T - P_{H_2O}}}{\frac{P^*_{H_2O}}{P_T - P^*_{H_2O}}} 100 = \frac{\frac{0.874}{30 - 0.874}}{\frac{5.878}{30 - 5.878}} 100$$

$$(a) \quad \boxed{= 12.3\%}$$

(c) Dew point is the temperature at which vapor first condenses on cooling at constant humidity, hence $p^* = 0.874$ in Hg $\boxed{\sim 75^\circ\text{F}}$

4.110

From steam tables, $p^*_{w90^\circ\text{F}} = 0.6982$ psia. Assume constant pressure during the process.

Partial pressure of water, $p_w = (0.85) p^*_{w90^\circ\text{F}} = 0.593$ psia

Partial pressure of dry air, $p_{\text{dry air}} = \text{Total pressure} - p_w = 14.696 - 0.593 = 14.103$ psia

(a) Molal humidity

$$= \frac{\text{mol of water vapor}}{\text{mol of dry air}} = \frac{n_w}{n_{\text{dry air}}} = \frac{p_w}{p_{\text{dry air}}} = \frac{0.593}{14.013} = \boxed{0.042}$$

(b) Humidity

$$= \frac{\text{lb of water vapor}}{\text{lb of dry air}} = \frac{0.042 \text{ lb mol } H_2O}{\text{lb mol dry air}} \left| \frac{18 \text{ lb } H_2O/\text{lb mol } H_2O}{29 \text{ lb air}/\text{lb mol air}} \right| = \boxed{0.026}$$

(c) Percentage absolute humidity

$$= \frac{\text{actual molal humidity}}{\text{molal humidity at saturation}} = \frac{\frac{p_w}{(p_T - p_w)}}{\frac{p^*_{w90^\circ\text{F}}}{p_T - p^*_{w90^\circ\text{F}}}} = \frac{\frac{0.593}{14.103}}{\frac{0.698}{13.998}} = \boxed{0.843 \text{ or } 84.3 \text{ percent}}$$

(d) Saturation temperature or the dew point is the temperature at which the vapor pressure of water will become equal to the existing partial pressure of 0.593 psia.

By interpolation dew point $\boxed{= 84.8^\circ\text{F}}$

(continued)

$$= 33.46 (315.6 - 15.6) + \frac{0.6880 \times 10^{-2}}{2} (315.6^2 - 15.6^2) \\ + \frac{0.7604 \times 10^{-5}}{3} (315.6^3 - 15.6^3) - \frac{3.593 \times 10^{-9}}{4} (315.6^4 - 15.6^4)$$

$$\Delta \hat{H} = 1.045 \times 10^4 \text{ J/g mol}$$

$$\frac{1.045 \times 10^4 \text{ J}}{\text{g mol}} \left| \frac{454 \text{ g mol}}{\text{lb mol}} \right| \frac{9.484 \times 10^{-4} \text{ Btu}}{\text{J}} = 4.499 \times 10^3 \text{ Btu/lb mol}$$

For CO_2 in Btu/(lb mol)(°F):

$$\Delta \hat{H} = \int_{60}^{600} (8.448 + 0.5757 \times 10^{-2} T - 0.2159 \times 10^{-5} T^2 + 0.3059 \times 10^{-9} T^3) dT$$

$$= 8.448 (600 - 60) + \frac{0.5757 \times 10^{-2}}{2} (600^2 - 60^2) - \frac{0.2159 \times 10^{-5}}{3} (600^3 - 60^3) \\ + \frac{0.3059 \times 10^{-9}}{4} (600^4 - 60^4)$$

$$\Delta \hat{H} = 5.442 \times 10^3 \text{ Btu/lb mol}$$

$$\Delta H = (4.499 \times 10^3 \text{ Btu/lb mol}) (6.00 \text{ lb mol}) + (5.442 \times 10^3 \text{ Btu/lb mol}) (4.00 \text{ lb mol})$$

$$\boxed{\Delta H = 4.88 \times 10^4 \text{ Btu}}$$

5.56

$^{\circ}\text{K}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$	
423	150.0	302	vapor
353.3	80.1	176	↓ satd vapor → satd liquid
278.7	5.5	42	↓ satd liquid → satd solid
253.0	-20.0	-4	↓ solid

Basis: 1 g mol

From Table D.1 in the Appendix.

Benzene properties:

Mol. wt.	78.11	Boiling point	353.26 K
Melting point	278.69 K	$\Delta H_{\text{vaporization}}$	30.76 kJ/g mol
ΔH_{fusion}	9.84 kJ/g mol		

K	$^{\circ}\text{C}$
423	150
353.26	80.11
278.69	5.54
253	-20

Heat Capacity Equation Coefficients:

	a	b	c	d	T
Benzene(g)	74.06	32.95×10^{-2}	-25.20×10^{-5}	77.57×10^{-9}	$^{\circ}\text{C}$
Benzene(l)	62.55	23.9×10^{-2}			K

The C_p equation is in $^{\circ}\text{C}$ hence the limits on integration should be in $^{\circ}\text{C}$. $\Delta H_1 = \int_{423}^{353} (74.06 + 32.95 \times 10^{-2}T - 25.20 \times 10^{-5}T^2 + 77.57 \times 10^{-9}T^3) dT =$

$$-11,790 \text{ J/g mol}$$

Condensation

$$\Delta H_2 = -3.076 \times 10^4 \text{ J/g mol}$$

Liquid

$$\Delta H_3 = \int_{353.26}^{278.69} (62.55 + 23.4 \times 10^{-2}T) dT = -10,180 \text{ J/g mol}$$

(continued)

Solutions-Chapter-5

5.92

	$\Delta H_{\text{Rxn}}(\text{J})$
(-b) $\text{C}_3\text{H}_8(\text{g}) \rightarrow \text{C}_3\text{H}_6(\text{g}) + \text{H}_2(\text{g})$	+126,000
(+a) $\text{HBr}(\text{g}) + \text{C}_3\text{H}_6(\text{g}) \rightarrow \text{C}_3\text{H}_7\text{Br}$	-84,441
(+c) $\text{H}_2(\text{g}) + \text{Br}(\text{g}) \rightarrow 2\text{HBr}(\text{g})$	-72,466
(-d) $\text{Br}(\text{g}) \rightarrow \text{Br}(\text{l})$	-30,710
Total	-61,616

5.93

1 g mol propylene

	$\Delta H^\circ(\text{kJ})$								
(5) $3[\text{C}(\text{graphite}) + {}^3\text{O}_2(\text{g}) \rightarrow {}^3\text{CO}_2(\text{g})]$	$-393.5] \times 3 = -1180.5$								
(2) $[\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\ell)]$	$-2220.0] \times 1 = -2220.0$								
Subtract									
$[3 \text{C}(\text{graphite}) + 4 \text{H}_2\text{O}(\ell) \rightarrow \text{C}_3\text{H}_8(\text{g}) + 2 \text{O}_2(\text{g})]$	$1039.5] \times 1 = 1039.5$								
(3) $[\text{H}_2(\text{g}) + 1/2 \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\ell)]$	$-285.8] \times 4 = -1143.2$								
Add									
$3 \text{C}(\text{graphite}) + 4 \text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8$	-103.7								
$\text{C}_3\text{H}_6 + \text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8$	-123.8								
Subtract									
(1) $3 \text{C}(\text{graphite}) + 3 \text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_6(\text{g})$	+20.1								
a. ΔH°_f of $\text{C}_3\text{H}_6 =$	20.1 kJ / gmol								
Basis: 1 g mol C_3H_6									
b. $\text{C}_3\text{H}_6(\text{g}) + 9/2 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2 + 3 \text{H}_2\text{O}(\ell)$	$\Delta H_c = \sum(\Delta H_f)_{\text{prod}} - \sum(\Delta H_f)_{\text{react}}$								
	<table> <tr> <td>No. 2</td> <td>-2220.0</td> </tr> <tr> <td>+No. 1</td> <td>-123.8</td> </tr> <tr> <td>-No. 3</td> <td>-(-285.8)</td> </tr> <tr> <td></td> <td>-2058.0</td> </tr> </table>	No. 2	-2220.0	+No. 1	-123.8	-No. 3	-(-285.8)		-2058.0
No. 2	-2220.0								
+No. 1	-123.8								
-No. 3	-(-285.8)								
	-2058.0								
$\Delta H_c = 3(-393.5) + 3(-285.8) - (20.1 + 0) =$									
	-2058.0 kJ / gmol								

$$\begin{array}{l} \text{IN: } \text{C}_4\text{H}_{10}(\text{g}) \quad 1 \text{ lb mol} \\ \text{air: } 6.5 \text{ lb mol O}_2 \\ \quad \frac{.5}{.21} \text{ lb mol N}_2 = \frac{24.45}{30.95} \text{ lb mol N}_2 \end{array}$$

$$\text{H}_2\text{O}(\text{g}) \quad p_{\text{H}_2\text{O}} = 0.461 \text{ psia} \quad \frac{p_{\text{H}_2\text{O}}}{p_{\text{gas}}} = \frac{0.461}{14.235} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{gas}}} = \frac{n_{\text{H}_2\text{O}}}{30.95}$$

$$p_T = 14.69 \text{ psia}$$

$$p_{\text{gas}} = 14.697 - .461 = 14.235 \quad n_{\text{H}_2\text{O}} = 1.00 \text{ lb mol}$$

OUT:

$$\text{CO}_2: 4 \text{ lb mol}$$

$$\text{N}_2: 24.45 \text{ lb mol}$$

$$\text{H}_2\text{O}: 1.00 + 5 = 6.00 \text{ lb mol}$$

$$Q + \dot{W} = \Delta H = \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

Energy balance

Let system be combustion system

Then Q^* for water being heat is

$$Q^* = \Delta H = 12.5 \text{ lb} [1134.3 - 45.0] = 13,616 \text{ Btu/lb C}_4\text{H}_{10}$$

 Q_{radn} = ignore for the moment - it is small

$$\text{Enthalpies in } n_i (\Delta \hat{H}_{\text{sensible}} + \Delta \hat{H}_f^*) = \Delta \hat{H}_{\text{in}} \left(\frac{\text{Btu}}{\text{lb mol}} \right)$$

$n\text{-C}_4\text{H}_{10}(\text{g})$	$[-124,730 + (1582-1030)]$	1	=	-124,178
$\text{O}_2(\text{g})$	$[0 + (2634-315.1)]$	6.5	=	15,073
$\text{N}_2(\text{g})$	$[0 + (2570-312.2)]$	24.45	=	55,203
$\text{H}_2\text{O}(\text{g})$	$[-241,826 + (3001-360.5)]$	1.00	=	239,186
				-293,087

Enthalpies out (assume 1500°F)

$\text{CO}_2(\text{g})$	$[-393,510 + (16,860-392.2)]$	4	=	-1,508,169
$\text{N}_2(\text{g})$	$[0 + (10,799-312.2)]$	24.45	=	256,402
$\text{H}_2\text{O}(\text{g})$	$[-241,826 + (13,140-360.5)]$	6.00	=	-1,374,279
				-2,626,046

(continued)

$$\Delta H_{\text{prod}} = 4350.36 \text{ kJ}$$

$$\text{Assume } T = 2250 \text{ K}$$

Comp.	g mol	$\Delta \hat{H}$ (kJ/g mol)	$\Delta \hat{H}_f^\circ$ (kJ/g mol)	ΔH (kJ)
CO ₂	7.008	(107,738 - 912)	-393.51	
H ₂ O	7.446	(85,855 - 837)	-241.826	
SO ₂	0.031	(105,562 - 984)	-296.90	
N ₂	40.36	(65,981 - 728)	0	

$$\text{Assume } T = 2500 \text{ K}$$

CO ₂	7.008	(123,176 - 912)	-393.51
H ₂ O	7.446	(98,867 - 837)	-241.826
SO ₂	0.031	(119,871 - 984)	-296.90
N ₂	40.36	(75,060 - 728)	0

$$T = 2395 \text{ K}$$

c. Coke Basis: 100 g

In: C = 95 g ash = 5 g
 = 7.917 g mol
 C + O₂ → CO₂
 O₂ req'd = 7.917 g mol
 N₂ = 29.782 g mol

Out: CO₂ = 7.907 g mol
 N₂ = 29.782 g mol

In:

ΔH_{react}

Comp.	g or mol	C_p or ΔH (kJ)	ΔT	ΔH (kJ)	$\Delta \hat{H}_f^\circ$	ΔH
C	7.917	11 (J/(g·mol) (K)	-7	-0.6096	0	
ash	5 g	1.15 (J/(g) (°C)	-7	-0.040	?	
O ₂	7.917	(.527 - .732)		-1.623	0	
N ₂	29.782	(.524 - .728)		-6.075	0	
		Total		-8.348		

Out:

$$\text{Assume } T = 2250 \text{ K}$$

Comp.	mol	ΔH (J/g mol)	ΔH (kJ)	$\Delta \hat{H}_f^\circ$	ΔH
CO ₂	7.917	(107,738 - 912)	845.74	-393.51	
N ₂	29.782	(65,981 - 728)	1,943.37	0	
ash	5 g	$C_p \Delta T = 1.15 (527 - 25)$	2.80	?	
		Total	2,791.91		

3.20

Basis: D=100 lb

 $x_1 \quad x_2 \quad x_3$

Coefficient matrix is

$$\begin{bmatrix} 0.5 & 0 & 0 & 1 & 1.4 \\ 90.0 & 10.0 & 0 & 1 & 31.2 \\ 5.0 & 85.0 & 8.0 & 1 & 53.4 \\ 0 & 5.0 & 80 & 1 & 12.6 \end{bmatrix}$$

3 by 3 for 1st 3 rows

No unique solution exists with 5 equations and 3 variables. A least squares solution could be determined or the 3 equations with the most accurate data solved. You can see that if you solve the last 3 equations formed from the last 3 rows and substitute the answer into the equation formed from the second row, the equation does not balance. More formally

The rank of the coefficient matrix is 3

The rank of the augmented matrix is 4 or 5

Hence no unique solution exists.

3.21

a) Up to 5 compound mass balances can be made. In each stream, the $\sum w_i = 1$ or $\sum m_i = \text{stream value}$, and one mass (or mass fraction) can be solved for each stream.

The total number of variables whose values are unknown is: 10 concentrations and 4 streams, and the number of balances is:

One set of measurements could be to measure concentrations.

A: HNO_3 , H_2SO_4 , (H_2O obtained by difference from 1)

B: H_2SO_4 (H_2O obtained by difference from 1)

C: Nothing needed.

D: Nothing needed.

E: CaSO_4

Let A,B,C,D and one composition in E be unknown.

Specifications required: $14 - 10 = 4$.

b) NO

Solutions - Chapter 6

		m	C_p	ΔT	kJ
ΔH_{In} :	n-C ₇ H ₁₆ vapor	100	(1.88)	(425 - 98.6)	61,360
	ΔH_{vap} at 98.6°C	(100)	(318)		31,800
	n-C ₇ H ₁₆ liquid	100	(2.13)	(98.6 - 25)	<u>15,680</u>
					<u>108,840</u>
ΔH_{Out} :	n-C ₇ H ₁₆ vapor	85.0	(1.88)	(425 - 98.6)	52,160
	ΔH_{vap} at 98.6°C	85.0	(318)		27,030
	n-C ₇ H ₁₆ liquid	85.0	(2.13)	(98.6 - 25)	13,330
	Toluene vapor	13.8	(2.30)	(425 - 110.8)	9,970
	ΔH_{vap} 110.8°C	13.8	(364)		5,020
	Toluene liquid	13.8	(2.22)	(110.8 - 25)	2,630
	H ₂ (g)	0.60	[29.2 (425 - 0) - (28.7) (25.0)]		<u>7,410</u>
					<u>117,550</u>

$$\Delta H_{\text{Rxn}} = (1000) (236.4) (0.15) = 35,460 \text{ kJ}$$

$$Q = 117,550 - 108,840 + 35,460 = 44,170 \text{ kJ/100 kg n-heptane fed}$$

(b) Energy Balances on extractor (ref. 25°C)

10 kg of solv. is used per kg of Toluene
So solvent used = $10 \times 13.8 = 138 \text{ kg}$
mass of Toluene = 138 kg

In:	n-C ₇ H ₁₆	85	(2.13)	(18 - 25)	-1,267
	toluene	13.8	(2.22)	(18 - 25)	- 215
	solvent	138	(1.67)	(38 - 25)	<u>2,996</u>
					<u>1,514</u>

Out:	n-C ₇ H ₁₆	85	(2.13)	(T - 25)	
	toluene	13.8	(2.22)	(T - 25)	442.15 (T - 25)
	solvent	138	(1.67)	(T - 25)	

Heat of Solution: (-23 kJ/kg) (13.8)

-317

$$\Delta H_{\text{prod}} - \Delta H_{\text{react}} + \Delta H_{\text{soln}} = 0$$

$$442.15 (T - 25) - 1,514 + (-317) = 0$$

(continued)

Solutions - Chapter - 3

System: Overall

(4)

or

(3)

Unknowns: $W, P, x_{C_2H_4O_2}^P, x_{H_2O}^P$ (assuming use $\sum x_i^P = 1$)

(ok)

Balances: C, H, O

(4)
plus



$$C: 100[0.525(2) + 0.475(2)] = P[0.70(2) + x_{C_2H_4O_2}^P(2)]$$

$$H: 100[0.525(2) + 0.475(4)] + W(2) = P[0.70(6) + x_{C_2H_4O_2}^P(4) + x_{H_2O}^P(2)]$$

$$O: W(1) = P[0.70(1) + x_{C_2H_4O_2}^P(2) + x_{H_2O}^P(1)]$$

$$0.70 - x_{C_2H_4O_2}^P - x_{H_2O}^P = 0$$

To make eqns. linear, let:

$$\left. \begin{aligned} P x_{C_2H_4O_2}^P &= n_{C_2H_4O_2} \\ P x_{C_2H_4O_2}^P &= n_{C_2H_4O_2} \\ P x_{H_2O}^P &= n_{H_2O} \end{aligned} \right\} \sum = P$$

and introduce in above eqns

$$0.70P + n_{C_2H_4O_2} + n_{H_2O} = P$$

$$\left. \begin{aligned} 200 &= 1.40P + n_{C_2H_4O_2} \\ 295.0 &= 4.20P - 2W + 4n_{C_2H_4O_2} + 2n_{H_2O} \\ 0 &= 0.70P - W + 2n_{C_2H_4O_2} + n_{H_2O} \\ n_{C_2H_4O_2} + n_{H_2O} &= 0.30P \end{aligned} \right\} \begin{aligned} P &= 105.36 \\ W &= 131.61 \\ n_{C_2H_4O_2} &= 26.25 \\ n_{H_2O} &= 5.36 \end{aligned} \text{ Moles}$$

System mixing point

unknowns: $R, F_2, x_{C_2H_4}^R$

Balances

$$F_2 = 18.75 + 125 = 143.75 \text{ kg mol}$$

Omit H_2 balance (Use C_3H_6)

Absorption/distillation tower

$$C_3H_6: \quad n_{C_3H_6}^{F_3} = F_5 = 50 \text{ kg mol}$$

$$H_2: \quad n_{H_2}^{F_3} = F_4 = 50 \text{ kg mol}$$

$$\text{total:} \quad F_3 = F_4 + F_5 + F_6 = 50 + 50 + 93.75 = 193.75 \text{ kg mol}$$

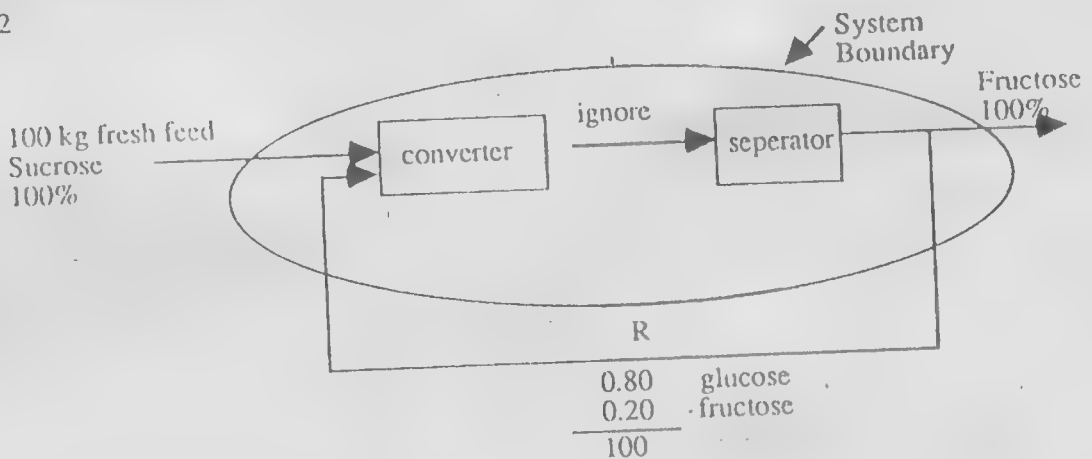
$$n_{C_3H_6}^{F_3} = 193.75 - 100 = 93.75 = F_6$$

Summary (all kg mol):

(a)	$F_1 = 50$	$F_4 = 50$
	$F_2 = 143.75$	$F_5 = 50$
	$F_3 = 193.75$	$F_6 = 93.75$

(b) 100% (no C_3H_6 exists)

3.92



This is a steady state problem with reaction and recycle.

Step 1, 2, 3, and 4:

This is a steady state problem. The balance will be in mass since composition are given as mass fractions.

Step 5:

Basis: 100 kg fresh feed

(continued)

Read from this graph, the v.p. is close to $101.65 = 44 \text{ atm}$

This procedure is really not accurate, as 44 seems relatively much larger than 29.

4.76

 27°C

$p^* = 3.536 \text{ kPa}$

dry N_2 27°C

$p = 101.3 \text{ kPa}$

$$p_T = p_{\text{N}_2} + p_{\text{H}_2\text{O}} = (101.3 + 3.536) \text{ kPa} = 104.8 \text{ kPa}$$

$$(b) \frac{n_{\text{H}_2\text{O}}}{n_{\text{N}_2}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{N}_2}} = \frac{3.536 \text{ kPa}}{101.3 \text{ kPa}} = 0.0349$$

4.77

 $T = -20^\circ\text{C}$

$p^* = 141.1 \text{ mmHg}$

 O_2 N_2 C_6H_{14}

$p_i = 760 \text{ mmHg}$

$p_{\text{air}} = 760/14.1 = 745.9 \text{ mmHg}$

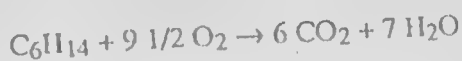
$p_{\text{C}_6\text{H}_{14}} = p^*_{\text{C}_6\text{H}_{14}} = 14.1 \text{ mmHg}$

Basis: 760 mol saturated gas

$p \Rightarrow \text{moles}$

O_2	.21 (745.9)	= 156.6
N_2	.79 (745.9)	= 589.3
C_6H_{14}		= $\frac{14.1}{760}$

For complete combustion



14.1 mol C_6H_{14} required 14.1 (9.5) = 134 mol O_2 required

$$156.6 - 134 = 22.60 \text{ mol } \text{O}_2 \text{ excess}$$

$$\frac{22.60}{134} \times 100 = 17\%$$

$$\frac{1.729 \times 10^{-4} \text{ g mol Hg}}{1 \text{ g mol Hg}} \left| \frac{200.59 \text{ g}}{1 \text{ g}} \right| \frac{1000 \text{ mg}}{1 \text{ g}} = 38.14 \text{ mg Hg}$$

$$V = \frac{nRT}{p} = \frac{99.5 \text{ g mol air}}{99.5 \text{ kPa}} \left| \frac{293.15 \text{ K}}{(\text{kg mol}) (\text{K})} \right| \frac{8.314 \text{ (kPa)(m}^3\text{)}}{1000 \text{ g}} = 2.44 \text{ m}^3 \text{ at } 20^\circ \text{C and } 99.5 \text{ kPa}$$

$$15.65 \frac{\text{mg}}{\text{m}^3} \text{ at } 20^\circ \text{C and } 99.5 \text{ kPa.}$$

Level is not acceptable.

A mercury spill can be cleaned up reasonably effectively by dusting with sulfur, then vacuuming with a vacuum cleaner specifically designed for mercury pick-up, which prevents the escape of mercury vapor.

The instructor should point out to the student that the assumption of the "no ventilation" is not a very good approximation unless the surface of the mercury is rather large or there is truly no ventilation in the storeroom.

4.85

Assume equilibrium.

At 75°F , from the Antoine equation, the vapor pressure of benzene is 90 mmHg. Assume the barometer is 760 mm Hg abs.

$$\frac{\text{mol Bz}}{\text{mol air}} = \frac{p_{\text{Bz}}}{p_{\text{t}} - p_{\text{Bz}}} = \frac{90}{760 - 90} = 0.13 \frac{\text{mol Bz}}{\text{mol air}}$$

a) The OSHA limit is 1 ppm over 8 hours. The above greatly exceeds this limit.

b) No, because the garage is probably not well ventilated, and also if a water heater is in the garage, the LEL (Lower Explosive Limit) may be exceeded.

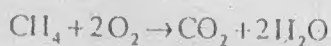
4.86

Steps: 1,2,3,4:

Process is steady state with a reaction.

(continued)

4.87



$$\frac{0.8335 \text{ mol N}_2}{0.79 \text{ mol N}_2} \left| \frac{0.21 \text{ mol O}_2}{2 \text{ mol O}_2} \right| \frac{1 \text{ mol CO}_2}{2 \text{ mol O}_2} = 0.1108 \text{ mol CO}_2$$

$$1 - 0.8335 - 0.1108 = 0.0597 \text{ mol H}_2\text{O}; 0.0057 (20) = 1.114 \text{ psia}$$

$$\text{Dew point} \approx \boxed{105^\circ\text{F}} \text{ at } 1.114 \text{ psia}$$

b) At constant temperature of 130°F , the gas must be compressed until the partial pressure increases and becomes equal to the vapor pressure in order to reach the point of condensation.

From Steam tables, the vapor pressure of water at 130°F is 2.223 psia.

The total pressure at which the partial pressure of water (mol fraction = 0.0557) will be 2.223 psia is

$$\frac{2.223}{0.0557} = \boxed{40.1 \text{ psia}} \quad P_{\text{H}_2\text{O}} = P_i Y_{\text{H}_2\text{O}}$$

4.88

$$\text{The sum } \sum \frac{y_i}{\text{LFL}_i} = 1.0$$

if the mixture is at the flash point.

Assuming Raoult's Law applies

$$y_i = \frac{p_i^* x_i}{p}$$

p_i^* = Vapor Pressure of i

p = Total Pressure

x_i = Liquid Phase Mole Fraction

y_i = Vapor Phase Mole Fraction

Assume $T = 65^\circ\text{F}$

Comp	x_i	p_i^* (Atm)	y_i	LFL
C_1	0.60	0.0123	0.00738	0.010
C_9	0.15	0.00365	0.000548	0.008
C_{10}	0.25	0.00116	0.000290	0.008

Data For
 p^* from
 Perry 6ed
 Table 3-8

(continued)

4.90

Basis: 100 mol Vapor

Comp	Mole %	p_i^* @ 66°F (mm) Hg	$\frac{y_i}{P_i}$
Ethane	10	57,600	1.73×10^{-6}
Propane	25	17,000	14.7×10^{-6}
iso-butane	30	7,250	41.5×10^{-6}
m-butane	30	5,370	46.5×10^{-6}
iso-pentane	10	2,400	41.5×10^{-6}
	100		$\Sigma = 145.9 \times 10^{-6}$

$$P_i = \frac{1}{\sum \frac{y_i}{P_i}} = \frac{1}{145.9 \times 10^{-6}} = 6880 \text{ mm Hg}$$

$$y_i = x_i \frac{P_i^*}{P_i} \Rightarrow x_i = \frac{y_i P_i}{P_i^*}$$

$$x_{C_2} = \frac{(0.1)(6880)}{(57,600)} = 0.012$$

$$x_{C_3} = \frac{(0.25)(6880)}{(17,000)} = 0.102$$

$$x_{\text{iso-C}_4} = \frac{(0.30)(6800)}{(7,250)} = 0.284$$

$$x_{\text{n-C}_4} = \frac{(0.25)(6880)}{(5370)} = 0.319$$

$$x_{\text{iso-C}_5} = \frac{(0.10)(6800)}{(2400)} = 0.286$$

Mole %
1.2
10.2
28.4
31.9
28.6
100.4

4.91

Basis: $p_{\text{Nap}}^* @ 180^\circ\text{F} = 460 \text{ mm Hg}$ $p_{\text{H}_2\text{O}}^* @ 180^\circ\text{F} = 388 \text{ mm Hg}$

$$P_{\text{Max}} = p_{\text{H}_2\text{O}} + p_{\text{Naptha}} = 460 + 388 = \boxed{848 \text{ mm Hg}} \quad (\text{a})$$

 $p_{\text{Naptha}}^* @ 160^\circ\text{F} = 318 \text{ mm Hg}$

(continued)

4.99

Use the flash vaporization relations given in the text to calculate the following:

(a)

$$V/F = 0.3 \quad T = 271.3^\circ\text{F}$$

	x	y
N-Hexane	.0632	.0192
N-Pentane	.2262	.1388
Iso-Pentane	.2191	.1555
N-Butane	.1869	.2307
Iso-Butane	.3046	.4559

(b)

$$V/F = 0.6 \quad T = 279.3^\circ\text{F}$$

	x	y
N-Hexane	0.0837	0.0275
N-Pentane	0.2520	0.1653
Iso-Pentane	0.2343	0.1772
N-Butane	0.1694	0.2204
Iso-Butane	0.2606	0.4096

4.100 The temperature range where the liquid and vapor can exist in equilibrium is between the bubble point and the dew point.

The solution is assumed to be ideal because it consists of hydrocarbons.

Vapor pressure data is taken from the 65th edition of the Handbook of Chemistry and Physics:

Component	Pressure (mm Hg)						
	760	1520	3800	7600	15200	30400	
propane	-42.1	-26.6	+1.4	26.9	58.1	94.8	Temp. (°C)
i-butane	-11.7	+7.5	39.0	66.8	99.5	-	
n-butane	-0.5	+18.8	50.0	79.5	116.0	-	
i-pentane	27.8	48.8	82.8	114.5	154.0	-	
n-pentane	36.1	58.0	92.4	124.7	164.3	-	

Using the program "ANTOINE" on the computer disk and the above data; the Antoine equation coefficients can be found for the form

$$p^*_i = \log^{-1} \left(A - \frac{B}{C + T} \right) \quad \text{where } T \text{ is in } ^\circ\text{C}$$

(continued)